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PERI-TETHYS PROGRAMME

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Publications Scientifiques du Muséum, Paris

Introduction

Ce volume spécial est le troisième et dernier de la série des volumes publiés par *Geodiversitas* dans le cadre du Programme international Péri-Téthys. Il est consacré aux données obtenues par les scientifiques russes ayant participés au programme. Les collaborations établies avec les collègues de la Communauté des États Indépendants (CEI) représentent un des apports originaux et importants de ce programme. En effet, ils ont permis des échanges d'informations mais aussi de méthodes. Le résultat est à l'actif du programme. Certains des résultats scientifiques sont publiés sous formes d'articles de corrélations stratigraphiques, dans les volumes publiés par le programme (*Geodiversitas* ou *Mémoires* du Muséum national d'Histoire naturelle). D'autres acquis apparaissent sur les cartes paléogéographiques (Atlas Péri-Téthys à paraître en 2000) qui synthétisent et illustrent cette fructueuse coopération.

Afin de présenter un ensemble homogène correspondant aux exigences de qualité requise par les responsables des publications du Muséum, toutes les figures de ce volume ont été redessinées ou reprises partiellement par les éditeurs. Cette tâche a été facilitée par l'intervention d'E. Cambreleng (Laboratoire de Géologie, MNHN), nous lui sommes reconnaissants de l'aide qu'elle a apportée.

Nous sommes très redevables au Muséum national d'Histoire naturelle qui nous a permis de concrétiser cette collaboration avec les collègues russes. Enfin, nous sommes heureux d'exprimer notre amicale gratitude à Hervé Lelièvre, rédacteur en chef, et Florence Kerdoncuff, assistante de rédaction pour leur compétence et leur professionnalisme.

Ce volume s'intègre dans la série des publications du Programme international Péri-Téthys :

This special issue is the third and last of the serie published by Geodiversitas *within the framework of the International Peri-Tethys Programme. It is devoted to the data obtained by the Russian scientists involved in the Programme. The collaborations established with the colleagues of the Independant States Community account for one of the original and main contributions of the Programme. Indeed, they allowed exchanges of informations and methods. Some results are published as stratigraphic correlations papers in the special volumes published by the Programme (*Geodiversitas *and* Mémoires du Muséum national d'Histoire naturelle*). Some others appear on the palaeogeographic maps (Peri-Tethys Atlas will be published in 2000) which synthetise and illustrate this fruitful cooperation.*

In order to present an homogeneous set which corresponds to the quality requests of the Museum publication team, all the figures were redrawn or picked again by the editors. We thank for her help for this work E. Cambreleng (Laboratoire de Géologie, MNHN).

We are indebted to the Museum national d'Histoire naturelle for his contribution in the concretisation of the collaboration with our Russian colleagues.

Finally, we would like to express our friendly gratitude to Hervé Lelièvre, Editor in Chief, and Florence Kerdoncuff, assistant editor, for their competence and professionalism.

This volume fits in the serie of Peri-Tethys International Programme publications.

Roure F. (ed.) 1994. — *Peri-Tethyan Platforms: Proceeding of the IFP Peri-Tethys Research Conference held in Arles, France, March 23, 1993.* Technip, Paris, 275 p.

Ziegler P. A. & Horwath F. (eds) 1996. — Peri-Tethys Memoir 2: Structure and prospects of Alpine Basins and Forelands. *Mémoires du Muséum national d'Histoire naturelle*, Paris 170, 547 p.

Crasquin-Soleau S. & De Wever P. (eds) 1997. —Peri-Tethys: stratigraphic correlations 1. *Geodiversitas* 19 (2) : 169-499.

Crasquin-Soleau S. & Barrier É. (eds) 1998. — Peri-Tethys Memoir 3: Stratigraphy and evolution of Peri-Tethyan Platforms. *Mémoires du Muséum national d'Histoire naturelle*, Paris 177, 262 p.

Crasquin-Soleau S., Izart A., Vaslet D. & De Wever P. 1998. — Peri-Tethys: stratigraphic correlations 2. *Geodiversitas* 20 (4) : 519-730.

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Crasquin-Soleau S. & Barrier É. 1999. — Peri-Tethys Memoir 5: New data on Peri-Tethyan sedimentary basins. *Mémoires du Muséum national d'Histoire naturelle*, Paris 182, sous presse.

Sylvie Crasquin-Soleau & Patrick De Wever

Correlations between Tatarian (Permian) type section (Russia) and the Salt Range (Pakistan): palynology and palaeomagnetism

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KEY WORDS
Palaeomagnetism,
palynology,
stratigraphic correlations,
Permian,
Salt Range,
Russian Platform.

ABSTRACT
The position of palaeomagnetic zones together with the occurrence of some miospore species in the section of Salt Range enables its correlation with the reference sections of Tatarian on the Russian Platform. So the Wargal Limestone corresponds roughly to the Vishkilsky Horizon (newly proposed name instead of Sevedrodvinsky Horizon) both boundaries of the former being slightly younger than the corresponding boundaries of the latter. The analogs of the lower part of Vishkilsky Horizon and of the whole early Tatarian are seemingly absent in the Salt Range. The Amb Formation is most probably of Kazanian age.

MOTS CLÉS
Paléomagnétisme,
palynologie,
corrélations stratigraphiques,
Permien,
Salt Range,
Plate-forme russe.

RÉSUMÉ
Corrélations entre la coupe type (Russie) du Tatarian (Permien) et le Salt Range (Pakistan) : palynologie et paléomagnétisme.
La position des zones paléomagnétiques associée à la présence de quelques espèces de miospores dans une coupe du Salt Range, permet des corrélations avec les coupes de référence du Tatarien de la Plate-forme russe. Ainsi le calcaire de Wargal correspond à l'horizon de Vishkilsky (nouveau nom de l'horizon de Sevedrodvinsky) dont les limites sont légèrement plus jeunes que celles du calcaire de Wargal. Les analogues de la partie inférieure de l'horizon de Vishkilsky et de l'ensemble du Tatarien sont absents dans le Salt Range. La Formation Amb est plus probablement datée du Kazanien.

INTRODUCTION

The well-known section of Permian and Triassic in the Salt Range (Pakistan) is in two respects of great importance for the palynostratigraphy. Firstly, it yields abundant and well-preserved miospores along with normal marine fauna. And although the calibration of this section in terms of common Tethys scale is not quite distinct as yet (Foster & Jones 1994), it still provides a hope on the correlation between marine and non-marine scales of Upper Permian and Lower Triassic.

Secondly, since the basic work by Balme (1970) it is evident, that the miospore assemblages from the Salt Range demonstrate a mixture of forms typical for different phytochoria of the past including those of both northern and southern hemispheres. It proves to be very useful for inter-regional palynostratigraphic correlations proper, especially in the Late Permian conditions of the highest phytogeographical differentiation of the Earth. So, Foster (1982) outlined the palynological correlation of the Salt Range with the Eastern Australia while Gomankov (1992) did the same for the Salt Range and the Russian Platform.

The last correlation may be however defined much more exactly due to the data on the palaeomagnetism of the section of Nammal Gorge (Salt Range) published by Haag & Heller (1991).

PALYNOLOGICAL AND PALAEOMAGNETIC CORRELATIONS

The Tatarian of the Russian Platform is usually subdivided into two substages and three horizons (from below upwards): Urzhumsky, Vishkilsky [the name "Vishkilsky Horizon" was recently proposed instead of the name "Severodvinsky Horizon", which turned to be invalid by nomenclature reasons (Gomankov 1997)], and Vyatsky, the first of them being early Tatarian and the two others being late Tatarian. Besides that the type section of the Tatarian at the Vyatka River was divided by Forsch (1963) into eleven units called "beds" each of them having received its own geographical name (Fig. 1). Due to the numerous palaeomagnetic studies of the Russian Platform Permian (e.g., Boronin 1979, 1990; Burov *et al.* 1996b), six palaeomagnetic zones were recognised in the Tatarian, three of them (R_1P, R_2P, R_3P) being of reversal polarity, one (NRP) of variable polarity, and two (N_1P, N_2P) of normal polarity (see Fig. 1 for relationship of this zonation with the above mentioned subdivisions of the Tatarian).

The boundaries of the palaeomagnetic zones in the Salt Range may be localised as following (Burov *et al.* 1996a, b). R_1P and NRP zones are not revealed. The R_2P/N_1P boundary lies in the lower part of Wargal Limestone (between the units 24 and 27 of Nammal Gorge section). The N_2P/R_2P boundary lies in the upper part of Wargal Limestone (between the units 17 and 18). The R_3P/N_2P boundary lies in the upper part of Chhidru Formation (in the lower part of the unit 72, approximately 18 m below the top of the formation), the structure of the upper zone being analogous to that of the R_3P zone of the Russian reference section.

As miospores are concerned, the Wargal/Amb boundary is characterised by the disappearance of *Hamiapollenites* and *Corisaccites* pollen grains as well as by the first appearance of *Lueckisporites virkkiae* Potonie & Klaus [here and below all ranges of miospore taxa in the Salt Range are adduced according to Balme (1970)]. At the Russian Platform *Hamiapollenites* and *Corisaccites* do not occur above the Tatarian/Kazanian boundary. At the same boundary appears *Lueckisporites virkkiae* (Fig. 2A), which ranges then throughout the whole Tatarian. Consequently only Kazanian (in any case Pre-Tatarian) age may be ascribed to the Amb Formation, the stratigraphic gap being assumed at the Wargal/Amb boundary corresponding at least to the whole early Tatarian. The presence of this gap can be confirmed by the data on fauna as well. Thus according to E. Ya. Leven (pers. comm.), the Amb Formation corresponds by its fauna to the Bolorian and the Wargal Limestone to the Midian of the Tethys marine scale, whereas the fauna of Murgabian type was not found at all in the Salt Range.

It is interesting that pollen grains of *Sulcatisporites nilsoni* Balme disappear at the

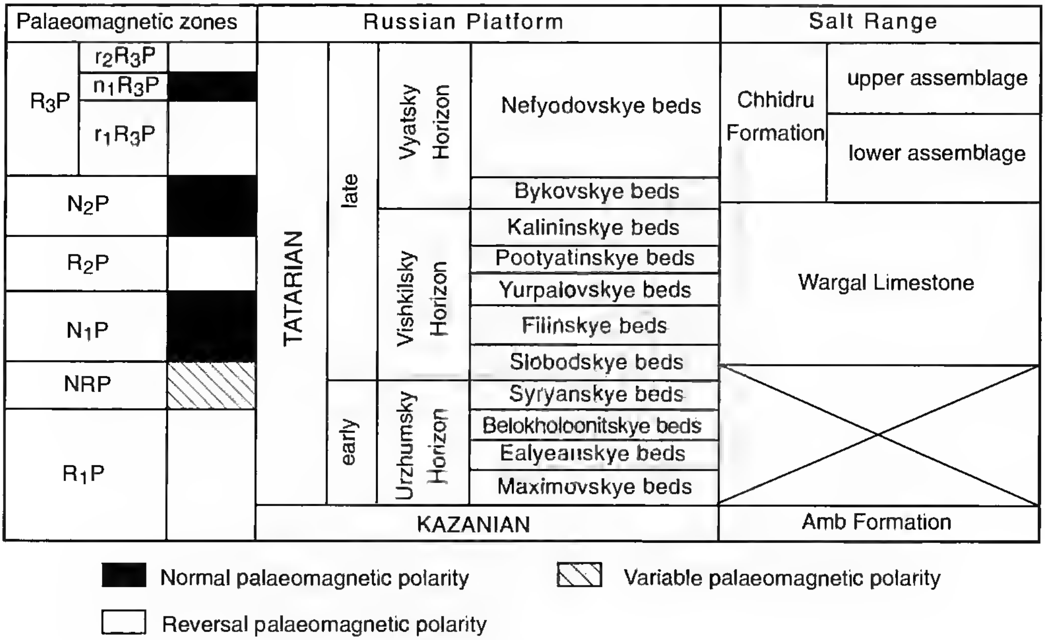

FIG. 1. — Correlating chart for the Upper Permian of Russian Platform and Salt Range.

Wargal/Amb boundary as well. These miospores demonstrate a striking similarity with "classic" forms of *Vesicaspora* ex gr. *magnalis* (Andreyeva) Hart (Fig. 3A) observed in the Kazanian of Russian Platform (Meyen & Gomankov 1971), and for instance they have the same split-like sulcus, whereas pollen grains of *V.* ex gr. *magnalis* from the Tatarian does not possess such a sulcus (Fig. 3C). It may be assumed that in the Kazanian and Tatarian of the Russian Platform the pollen grains designated as *V.* ex gr. *magnalis* belonged in fact to two different species being therefore of a big stratigraphic importance. It is also characteristic that these different types of pollen grains were attributed to different species of *Phylladoderma*: (1) the Kazanian one – to *P. meridionalis* S. Meyen and *P. arberi* Zalessky (Meyen & Gomankov 1971; Gomankov & Meyen 1980; Anonymous 1986); (2) the Tatarian one – to the species of subgenus *Aequistomia* (Anonymous 1986).

Other palynological changes indicated by Balme (1970) at the Wargal/Amb boundary (i.e. the disappearance of *Verrucosisporites* cf. *planiverrucatus* Imgrund and *Pyramidosporites racemosus* Balme as well as the appearance of *Punctatisporites* cf. *minutus* Ibrahim) give nothing for the correlation with the Russian Platform, where the mentioned species are absent.

The Chhidru/Wargal boundary finding itself on the palaeomagnetic grounds in the lower part of N_2P zone lies therefore somewhere near the boundary of Vyatsky and Vishkilsky horizons. In palynological respect it is characterised by the disappearance of the quasimonosaccate pollen grains of *Potoniesporites novicus* Bharadwaj and the appearance of the monolete spores of *Laevigatosporites callosus* Balme, *Polypodiisporites mutabilis* Balme, *Lunulasporites vulgaris* Wilson and pollen grains of *Densipollenites indicus* Bharadwaj (infraturma Monopolsacciti), *Klausipollenites schaubergeri* (Potonie & Klaus) Jansonius, *Cedripites priscus* Balme (infraturma Disacciatrileti), *Potoniesporites microcorpus* (Schaarschmidt) Clarke (infraturma Striatiti) and *Marsupipollenites triradiatus* Balme & Hennelly (infraturma Praecolpati). Of these species *L. callosus*, *P. mutabilis*, *L. vulgaris*, *D. indicus*, *P. microcorpus* and *M. triradiatus* are not known at the Russian Platform. *K. schaubergeri* appears

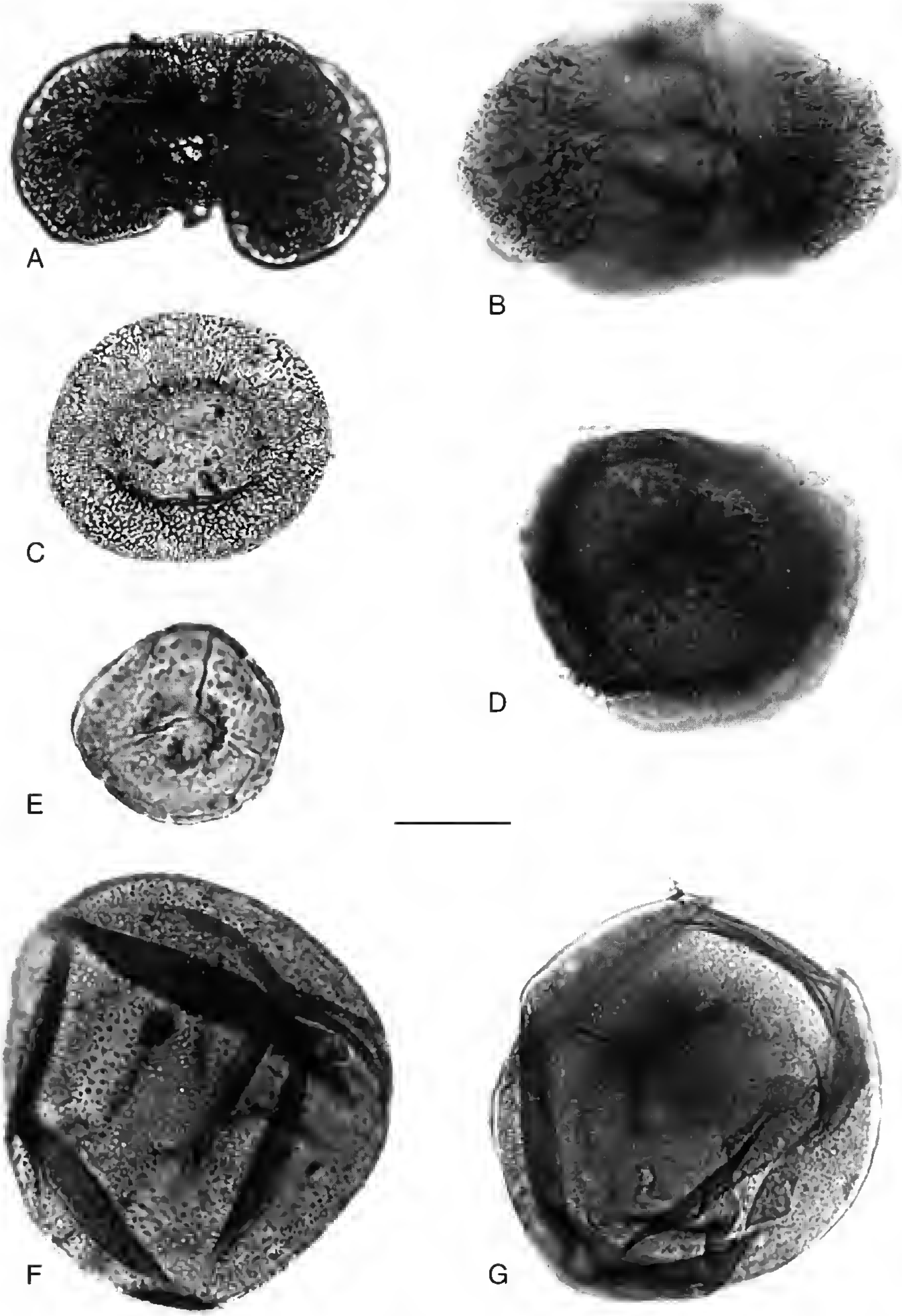

FIG. 2. — Miospores from the Kazanian and Tatarian of Russian Platform. All specimens are kept in the Geological Institute of the Russian Academy of Sciences, Moscow, Russia. **A**, *Lueckisporites virkkiae* Potonie & Klaus, spec. 4100/100-4-213, Urzhumsky Horizon; **B**, *Hamiapollenites* sp., spec. 4492/32b, the Kazanian; **C**, *Cordaitina* sp. (quasimonosaccate pollen grain), spec. 4388/1-3-1-1, Vyatsky Horizon; **D**, *Kraeuselisporites* sp., spec. 4552/371-4-184, Vyatsky Horizon; **E**, *Limatulasporites* (= *Nevesisporites*) *fossulatus* (Balme) Helby & Foster, spec. 3774/3-x-49-22, Vyatsky Horizon; **F**, *Osmundacidites senectus* Balme, spec. 4388/1-3-2-412, Vyatsky Horizon; **G**, *Calamospora* aff. *landiana* Balme, spec. 4552/371-4-70, Vyatsky Horizon. Scale bar: A, B, D-G, 0.02 mm; C, 0.04 mm.

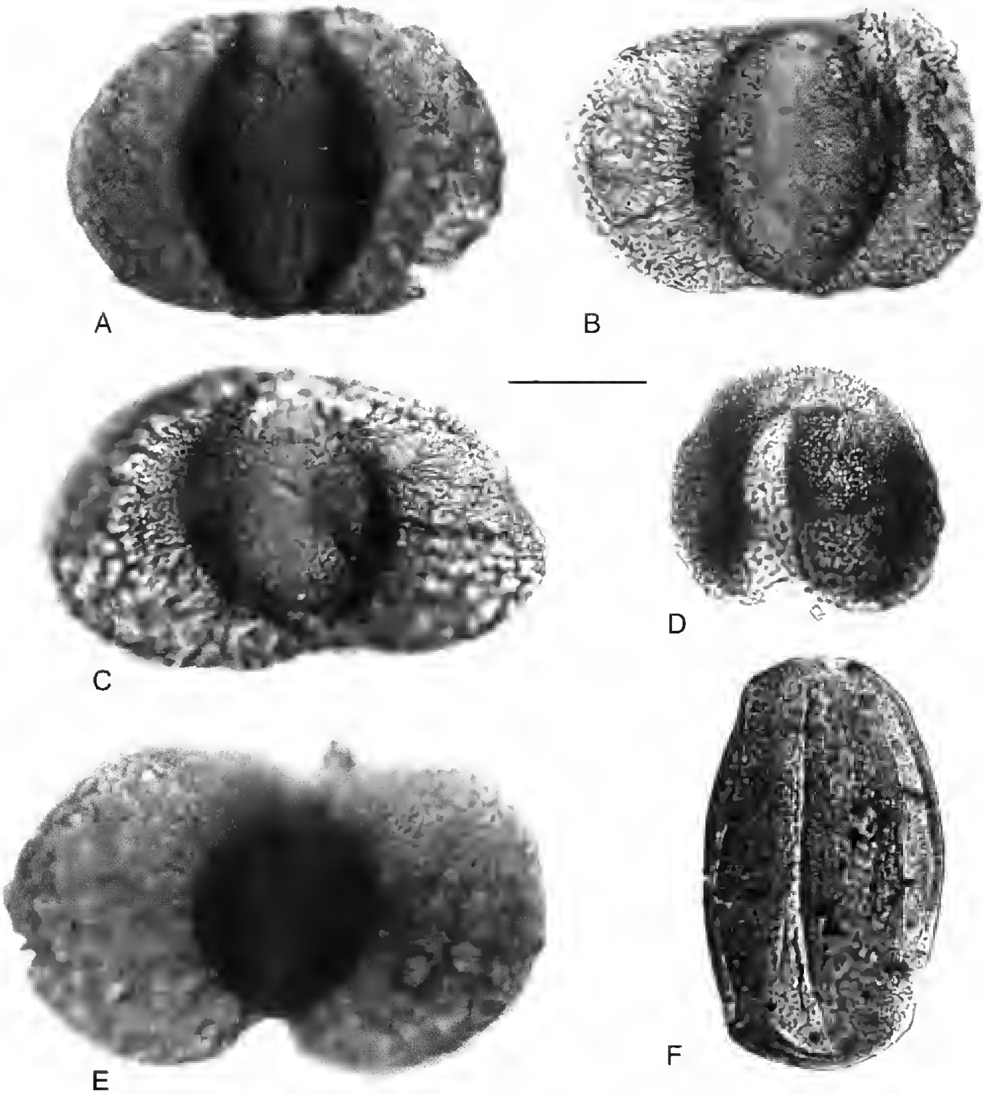

Fig. 3. — Miospores from the Kazanian and Tatarian of Russian Platform. All specimens are kept in the Geological Institute of the Russian Academy of Sciences, Moscow, Russia. **A**, *Vesicaspora* ex gr. *magnalis* (Andreyeva) Hart, pollen grain with a split-like sulcus, spec. 3775/246b-14, the Kazanian; **B**, *Falcisporites* sp., spec. 3774/3x-a(5A), Vyatsky Horizon; **C**, *Vesicaspora* ex gr. *magnalis* (Andreyeva) Hart, pollen grain without split-like sulcus, spec. 4552/371-4-47, Vyatsky Horizon; **D**, *Cedripites priscus* Balme, spec. 4552/371-4-148, Vyatsky Horizon; **E**, *Fimbraesporites* ? sp., spec. 4552/177-2-32, Vyatsky Horizon. Scale bar: A-C, E, F, 0.02 mm; D, 0.04 mm.

trustworthy at the Russian Platform only in the Vetluzhskaya Formation of Triassic age, i.e., it has confidently another stratigraphic range. Quasimonosaccate pollen grains (Fig. 2C) occur throughout the Tatarian, although its abundance decreases strongly upwards and it becomes exceptionally rare in the Vyatsky Horizon. As *Cedripites priscus* is concerned, the very similar pollen grains (Fig. 3D) are highly abundant at the socalled oxbow-lake level in the middle of Vyatsky Horizon, which yields most of palynological samples of Vyatsky age. However, *Cedripites* sp. is also known in Isady locality of Vishkilsky age. Miospore assemblage from the base of Vyatsky

Horizon was described only once by Molin & Koloda (1972) from Kalikino locality. This contains quasimonosaccate pollen *Florinites luberae* Samoilovitch (though as a single specimen) and seemingly lacks pollen which could be assigned to *Cedripites*. On these grounds, one may consider the Chhidru/Wargal boundary lying slightly higher than the base of Vyatsky Horizon but still lower than the oxbow-lake level, where several forms typical for the uppermost Chhidru Formation appear (see below).

It is noteworthy that the uppermost Chhidru Formation is characterised by a peculiar miospore assemblage, which plays an important part in the interregional correlations, especially concerning Gondwana (Foster 1982; Foster & Jones 1994). The exact position of this assemblage in the "Russian" scale was impossible to determine by pure palynological means since several species (*Nevesisporites fossulatus* Balme, *Kraeuselisporites* sp., *Osmundacidites senectus* Balme, *Calamospora landiana* Balme, *Pretricolpipollenites bharadwaji* Balme, *Fimbraesporites* ? sp., *Falcisporites stabilis* Balme), typical for it, were similar to miospores known from the Vyatsky Horizon (Figs 2D-G, 3B, E, F), while others [*Densoisporites* sp., *Lundbladispora obsoleta* Balme, *Gnetaceaepollenites sinuosus* (Balme & Hennelly) Bharadwaj, *Taeniaesporites noviaulensis* Leschik] appeared at the Russian Platform only from the base of Vetluzhskaya Formation (though pollen grains of *Ephedripites* are known in the Russian Platform Kazanian, in fact they do not occur in the Tatarian and appear in noticeable amounts also in the Vetluzhskaya Formation only). Balme (1970) did not define the precise range of this uppermost Chhidru assemblage, but it seems very likely, that there is a rather big unsampled interval between the uppermost samples of lower Chhidru assemblage and the lowermost samples of upper Chhidru assemblage. So the oxbow-lake level, from which the main large amount of palynological samples of Vyatsky Horizon comes, may well find itself in this unsampled interval of the Salt Range section. To judge from the distribution of Balme's samples in the Nammal Gorge, all samples with the upper assemblage come from the palaeomagnetic zone R_3P, while oxbow-lake level lies in the upper part of zone N_2P (at the boundary between the Bykovskye and Nefyodovskye beds). The boundary between the upper and the lower palynological assemblages of Chhidru Formation finds thus itself somewhere inside the Nefyodovskye beds.

As a result the stratigraphic correlation between the Russian Platform and the Salt Range may be represented as shown in the Figure 1.

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Permian and Triassic exotic limestone blocks of the Crimea

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Kotlyar G. V., Baud A., Pronina G. P., Zakharov Y. D., Vuks V. Ja., Nestell M. K., Belyaeva G. V. & Marcoux J 1999. — Permian and Triassic exotic limestone blocks of the Crimea, *in* Crasquin-Soleau S. & De Wever P. (eds), Peri-Tethys: stratigraphic correlations 3, *Geodiversitas* 21 (3) : 299-323.

ABSTRACT
Exotic limestone blocks of Permian and Triassic age occur in the Middle Triassic-Middle Jurassic Crimean olistostrome complex of the Marta and Alma River basins and in the Simferopol area. Rich assemblages of small foraminifers, fusulinids, brachiopods, rare ammonoids, and sphinctozoans occur in these blocks. Fossils from Permian blocks indicate the presence of zonal assemblages for the Bolorian, Kubergandian, Murgabian, Midian, Dzhulfian, and Dorashamian stages. The *Neoschwagerina simplex* fusulinid zone is extended upward based on the presence in our material of Kubergandian ammonoids with *Neoschwagerina simplex* Ozawa. Comparison of the fauna from Triassic blocks to assemblages from other regions of the Tethys indicates that the age is Late Triassic Rhaetian corresponding to the *Vandaites sturzenbaumi* ammonoid zone.

KEY WORDS
Upper Triassic, Rhaetian, Permian, exotic blocks, Crimea, foraminifers, fusulinids, brachiopods, ammonoids, sphinctozoans.

RÉSUMÉ
Les blocs exotiques calcaires du Permien et du Trias en Crimée.
Les blocs exotiques de calcaire permiens et triasiques de la Crimée appartiennent à l'unité olistostromale d'Eskiordin (Trias moyen-Jurassique moyen) et ont été trouvés dans les bassins-versant des rivières de Marta, d'Alma et dans la région du lac (réservoir) de Simferopol. Les blocs permiens contiennent des petits foraminifères et des fusulines ainsi que des brachiopodes, de rares ammonoïdes et des sphinctozoaires dont nous présentons l'inventaire. La distribution des assemblages fossilifères couvre la fin du Permien inférieur (Bolorien) ainsi que tout le Permien supérieur, du Kubergandien au Dorashamien. La présence conjointe d'ammonoïdes et de brachiopodes d'âge Kubergandien avec *Neoschwagerina simplex* Ozawa est signalée. L'analyse des micro- et macrofaunes des blocs triasiques ainsi que des comparaisons avec les faunes semblables d'autres régions téthysiennes permettent d'attribuer aux assemblages décrits un âge rhétien.

MOTS CLÉS
Trias supérieur, Rhétien, Permien, blocs exotiques, Crimée, foraminifères, fusulinides, brachiopodes, ammonoïdes, sphinctozoaires.

INTRODUCTION

For this study, our team investigated Permian and Triassic exotic limestone blocks occurring at several localities in the area between Simferopol and the Marta River Basin. Limestone samples containing remains of several different faunal groups were obtained. Carbonate microfacies were studied by A. Baud, small foraminifers by G. P. Pronina (Permian and Triassic) and V. Ja. Vuks (Triassic), brachiopods by G. V. Kotlyar, ammonoids by Y. D. Zakharov, sphinctozoans by G. V. Belyaeva, and fusulinids by V. I. Davydov and M. K. Nestell.

HISTORY

Fokht (1901) studied the oldest deposits then known from the Crimea. He named the "Taurida Beds", and dated them as Late Triassic. Moiseev (1939) named the Eskiorda Formation,

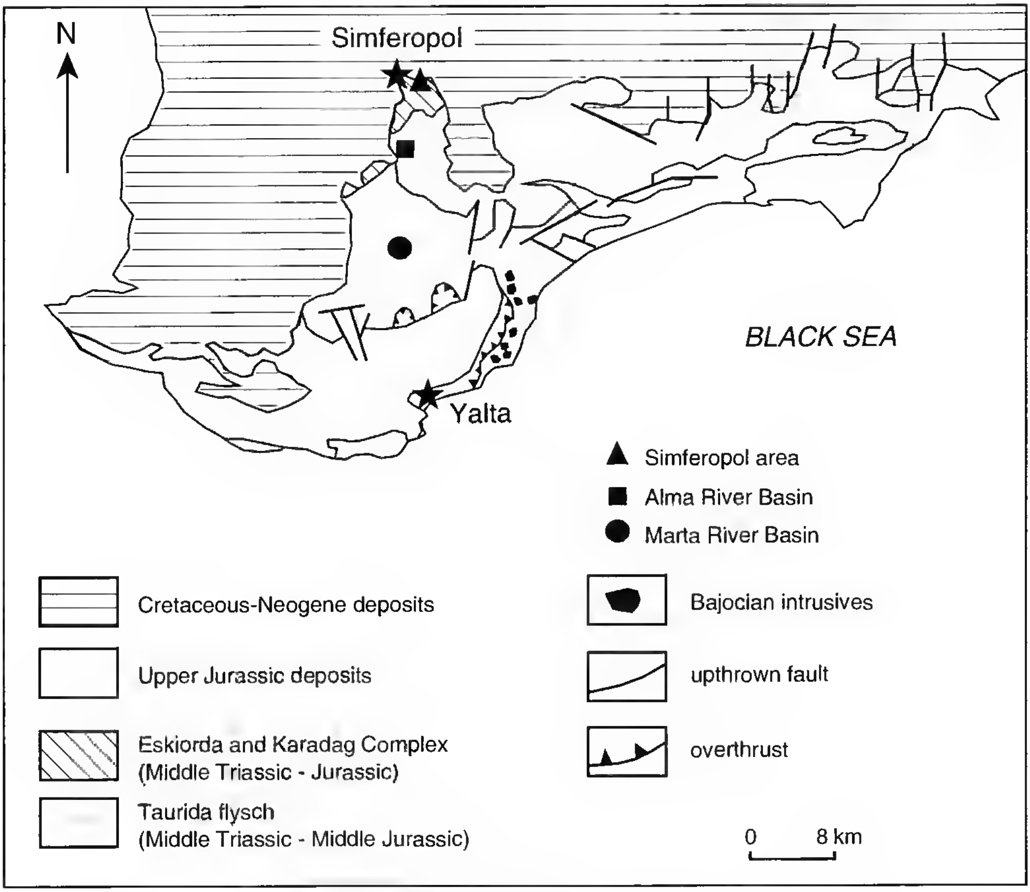

FIG. 1. — Sketch geological map of South Crimea (after Mileev *et al.* 1989).

a shallow-water conglomerate (Rhaetian-Liassic) facies present in the northern part of the Kacha uplift. Muratov (1949) divided the Taurida beds into three parts: (1) a lower unit of Late Triassic age; (2) a middle unit, the Eskiorda Formation; (3) an upper unit, both of early and middle Liassic age. Logvinenko *et al.* (1961) proposed a more detailed subdivision of the Taurida Series and considered the lower part to be of Early and Middle Triassic age.

Study of outcrops in the valley of the right tributary of the Bodrak River (Dagis & Shvanov 1965; Shvanov 1966) has shown that the Taurida Series rock ranges in age from Middle Triassic to Early Jurassic. The most common subdivision scheme of the Taurida Series has been given in "Geology of the USSR" (Anonymous 1969), where the Upper Triassic, Lower Taurida and the Liassic Upper Taurida (Eskiorda) formations were proposed with two types of lithofacies for each unit. Koronovsky & Mileev (1974) conducted research on the Eskiorda Formation in the Bodrak River Valley and proposed a broader Carnian-Pleinsbachian stratigraphic range for it. On this basis, they increased the rank of this unit to a Series and considered it as an equivalent of the Taurida Series rock; they also stated, that the Eskiorda Formation (or Series) in the Bodrak River area represented a tectonic melange.

GEOLOGICAL SETTING (Fig. 1)

The oldest stratigraphic unit cropping out in the

Crimean Mountains is the Taurida flysch of Middle Triassic to Toarcian age (Shalimov 1960, 1963). The underlying units and basement have never been observed, but geophysical seismic data indicates a thin carbonate-clastic unit overlying granitic basement (Muratov *et al.* 1984).
The Taurida flysch is overlain with a structural unconformity either by Upper Jurassic deposits in the south and east of the Kacha uplift, or by Lower Cretaceous deposits in the north and west. In some parts of the Kacha uplift, the Taurida flysch is allochthonously overlain by the Eskiorda unit. The Taurida flysch makes up the core of the Kacha uplift. Mileev *et al.* (1989) distinguished the Alma unit for the proximal flysch in the core of the uplift, and the overlying Patil unit for the distal flysch. The Alma unit is exposed in the Belbek, Kacha, Marta, Alma, Salgir and Bodrak River valleys. It consists of predominantly gray, thin bedded fine sandstone and shale with reworked coalified plants debris. Commonly, the Alma unit is exposed only in river valley floors; in the Bodrak River Valley it is recorded in the middle and upper parts of slopes, and there is overthrusting the Patil unit. In the Alma River (Drovyanka Village and near Partizanskoe Village) and Salgir River basins, the Alma unit contains a Carnian and lower Norian fauna. Near Drovyanka Village (Alma River Basin), middle Liassic foraminifers occur in the shale. Near the mouth of the Marta River, Pliensbachian crinoids occur, and in the flysch of the Petropavlovsk quarry, bivalve mollusks of Toarcian-lower Bajocian age have been described. The age of the Alma unit is considered to be Middle Triassic to Bajocian. The Patil unit is exposed only in the Bodrak River Valley and differs from the Alma unit by a greater thickness of flysch couplets with mudstone dominating the couplets. A middle Liassic to Aalenian fauna occurs near Prochladnoe Village.

The Taurida flysch and its Aalenian to Eocene stratigraphic cover are separated from the North Crimean cover units (Jurassic-Eocene) by the north dipping Eskiorda unit. Originally named and interpreted as the basal part of the Taurida flysch by Moiseev (1932), and later by Shalimov (1960, 1963), this unit has been recently mapped in detail and reinterpreted by Mileev *et al.* (1989) as a composite and dismembered tectonic complex. It is the best exposed within the Lozovaya shear zone of the Kacha uplift (northern part of the core) and north of it, but it also occurs overthrust above the Taurida flysch in the Bodrak and Marta River valleys. According to the lithological and biostratigraphical contents, these authors subdivided the Eskiorda tectonic complex into the Mender (Ladinian-Sinemurian), Dzhidair (Bajocian), Kichik (Norian), Chenk (Middle-Upper Triassic?), Saraman (Late Triassic-Bajocian) and Bitak (Toarcian-Bathonian) subunits. The lithology consists mainly of fine to coarse terrigenous clastics. The turbiditic flysch sequence characterises the lower subunits and was probably deposited in shallow marine conditions because coal and coarse sandstone occurs in the upper Saraman subunit (Mileev *et al.* 1989). These authors regard the Eskiorda complex as equivalent in age to the Taurida unit.
Most of the exotic limestone blocks occur in the Mender subunit and some in the Saraman subunit. They are interpreted as olistholiths (olistostromes for the older Carboniferous to Sinemurian part), and as tectonic incorporated blocks (melange) for the younger Late Liassic-Cretaceous part. Their origin is still controversial. Some geologists believe that they originated from the north (south of Scythian Plate margin), whereas others consider that they were transported from the south.
The Mender subunit (Ladinian-Sinemurian) is composed mainly of shale with thin beds of fine-grained quartzitic sandstone. It occurs in the northwestern part of the Kacha uplift, in the Bodrak, Alma and Salgir River valleys. The Saraman subunit is composed of highly mature, light gray, massive, quartzitic sandstone with beds of fine- and medium-pebbly conglomerate and with rare silty clay interbeds. It occurs on the northern slope and on the southern limb of the Kacha uplift, in the Salgir, Alma, Bodrak and Marta River valleys. Based on macro- and microfauna occurrences (Mileev *et al.* 1989), the Saraman is Late Triassic-early Bajocian in age.

HISTORY AND THE AGE INTERPRETATION OF THE EXOTIC BLOCKS

Fokht (1901) first recorded the occurrence of Permian limestone blocks within the Triassic-Jurassic complex. Previous researchers had assigned these blocks to different stratigraphic horizons of the Permian System. Toumansky (1931, 1935, 1937a, b) distinguished ammonoid, fusulinid, and trilobite assemblages in certain blocks, and studied the Permian faunas from these exotic blocks in the most detail. She considered them to belong to the biostratigraphic "horizons": Bodrakian, Soramanian, Burnian, and Martian. Initially, she presumed that the Soramanian assemblage was similar to that found in the Gaptank Formation in West Texas and to be of Late Carboniferous age (*Uddenites* zone). Subsequently, Toumansky (1941) concluded that the limestone with this ammonoid assemblage corresponded to the lower part of the Permian Leonard Formation in West Texas of North America, the lower part of the Bitauni Formation on Timor Island, and the upper part of Buztere beds in the Southeastern Pamirs. In her study of Permian ammonoids of the Central Pamirs, Toumansky (1963) correlated the Burnian and Martian ammonoid assemblages of the Crimea with the Kubergandian assemblage from the Pamirs. According to Bogoslovskaya (1984), the Burnian assemblage is similar to the ammonoid assemblage in the Kuberganda Formation of the Pamirs, and is Roadian in age. The so-called "Martian (Martovsky or Martinsky)" assemblage is considered to be Wordian.

The Late Triassic age of certain limestone block is mainly derived from occurrences of Anisian and Norian-Rhaetian brachiopods (Dagis 1963; Dagis & Shvanov 1965).

CRIMEA-PONTIDES (NORTHERN TURKEY) TENTATIVE CORRELATIONS (FIGS 2 , 3)

The Crimean Mountains and the central Pontides (Turkey) represent the conjugate rift margin of the Western Black Sea oceanic basin (Fig. 3).

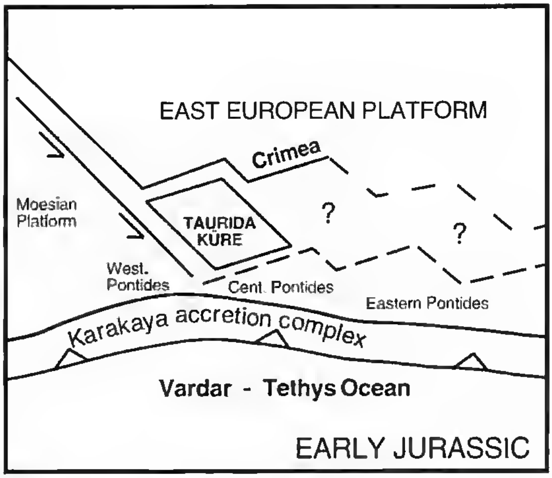

FIG. 2. — Early Jurassic reconstruction, following opening of Küre/Taurida basins; schematic and not scale (simplified and modified from Banks 1997).

Prior to the opening of the Western Black Sea oceanic basin initiated in Barremian-Aptian time and completed in Cenomanian time (Görür 1988), southern Crimea and central Pontides occupied neighbouring positions (Fig. 2, see also reconstruction schemes recently proposed by Banks and Robinson *in* Banks 1997).

In the Crimea (this paper) as well as in the central Pontides (Aydin *et al.* 1986; Yilmaz *et al.* 1997), there are occurrences of flyschoids successions. In the Crimean Mountains and the central Pontides, the oldest rocks exposed are a sequence of basinal turbiditic mudstones and siltstones of similar age (Triassic-Early Jurassic). These formations were disrupted during the Cimmerian orogenesis at the end of the Middle Jurassic (Sengör 1984).

As was proposed before (Marcoux & Baud 1996; Marcoux *et al.* 1993) the equivalent of the "Taurida flysch" from the Crimea would correspond to the Küre series of the Akgöl Formation (Aydin *et al.* 1986; Yilmaz *et al.* 1997) from the central Pontides. This hypothesis was proposed again recently (Robinson & Kerusov 1997).

At the moment, only Triassic exotic blocks (olistoliths) have been described within the Küre/Akgöl series, for instance Hallstatt facies limestones of late Anisian and Ladinian (Önder 1990; L. Krystyn, pers. comm. 1992). Future detail

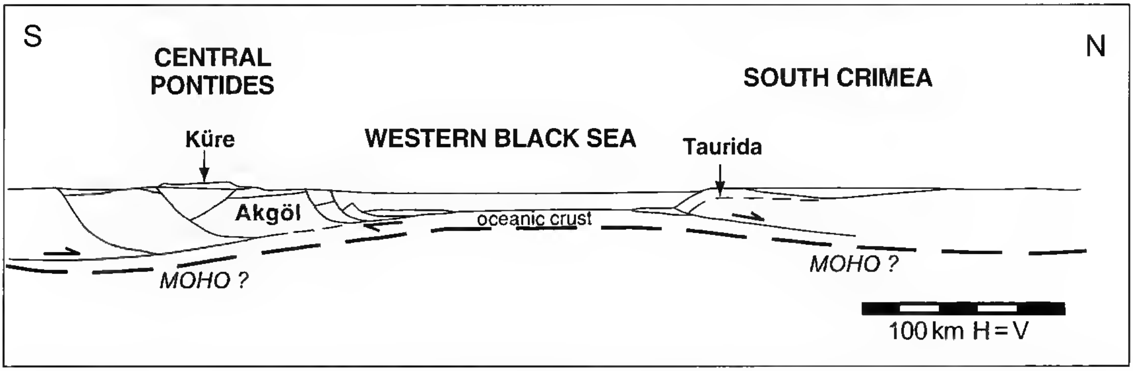

FIG. 3. — Schematic structural cross section of the eastern part of the western Black sea from northern Turkey (Central Pontides) to Crimea Mountains (South Ukraine) (simplified and modified from Banks 1997).

investigations might also demonstrate the occurrence of Late Palaeozoic blocks, similar in age to those from the Crimea described in this paper.

PERMIAN EXOTIC BLOCKS

Permian exotic blocks were studied in the Marta and Alma River basins and in the Simferopol area. Correlation of these blocks and locations of fossils are shown in Table 1.

MARTA RIVER BASIN

In limestone exposed on the slopes of Kichkhi-Burnu Mountain in the Marta River Basin, Toumansky (1941) recorded two "horizons with fauna" (fusulinids, ammonoids, trilobites) which she called Burnian and Martian. She correlated the Burnian "horizon" with the upper part of the Leonardian, and the Martian "horizon" with the Wordian. In later studies, it was ascertained that these so-called "horizons" were not valid, and the assemblages were correlated to the Permian Murgabian, Darvazian and Pamirian stages (Einor & Vdovenko 1959; Licharew 1966).

In the Marta River Basin, the largest Permian block (65 × 35 × 15 m) is located on the right flank of one of the right tributaries of the Marta River, 5 km upstream from the Verkhorechye Village (Loc. 110; Figs 4A, 5). Here light gray and pinkish-gray non-bedded algal-fusulinid (reefogenic?) limestone forms Kichkhi-Burnu Mountain. Several smaller blocks located nearby, also contain abundant and diverse foraminifers, brachiopods, trilobites, gastropods, and ammonoids. Some of these blocks contain distinct lithologies separated by breccia zones and contain different fossil remains. Peripheral parts display clastic textures (rounded and semirounded fragments of gray boundstone with light-colored carbonate cement), as well as micritic limestone of a pinkish or beige tint. The northwestern margin of the main block appears to contain the oldest sediments.

Loc. 110/sample 1

The limestone of this sample is a well-sorted skeletal grainstone containing calcareous algae, foraminifers, gastropods, calcareous sponges and brachiopod fragments. It is interpreted as being deposited in a high energy, shallow marine palaeoenvironment.

Small foraminifers. *Tuberitina collosa* Reitlinger, *Mendipsia conili* (Nguyen Duc Tien), *Endothyra* sp., *Climacammina valvulinoides* Lange, *Deckerella* sp. 2, *Tetrataxis* sp., *Globivalvulina graeca* Reichel, *Palaeotextularia pingguoensis* Lin, *P.* sp.(= *P. longiseptata* Lipina *in* Zheng 1986), *Pachyphloia sphaerula* Sosnina, *Langella* sp., *Neodiscus* aff. *N. milliloides* A. M.-Maclay.

Fusulinids. *Parafusulina vinogradovi* Leven, *P.* cf. *P. multiseptata* (Schelwien), *P.* aff. *P. nakamigavai* Morikawa & Horiguchi, *P.* aff. *P. yunnanica* Sheng, *P. crassispira* Leven, *P. murattbekovi* Leven, *P. undulata* Chen, *Armenina asiatica* Leven, *A. karinae* (Kochansky-Devide & Ramovs), *A. salgirica* A. M.-Maclay,

Tethyan scale		Assemblages	Marta River Basin												Alma River Basin							Simferopol area								
Leven 1980, 1996; Kotlyar & Pronina 1995		Toumansky 1931, 1941, 1963	110												129	112	113	122				123		111					125	
			1	2	3	4	5	6	7	8	9	10	20	21				a	b	c	d	2	3	1	2	3	3a	7	1	2
Dorashamian																	SF													
Dzhulfian															SF		F	SF	SF F	SF F										
Midian	Yabeina																				SF F									
Midian	Neoschwagerina margaritae	Martian																				F			SF F	F	SF F	SF		
Murgabian	Neoschwagerina craticulifera	Martian					SF F			Br																				
Kubergandian	Neoschwagerina simplex Praesumatrina	Burnian	SF F Br A ST	SF Br	F Br	SF F		SF F	SF F		SF F Br	Br A ST	SF F	SF F Br		A								F					SF F	F
Kubergandian	Cancellina cutalensis	Burnian	A													A														
Bolorian	Misellina claudiae	Soramanian																					F							

TABLE 1. — Distribution of fossil localities and correlation of Permian exotic blocks in the Crimea. **SF**, small foraminifers; **F**, fusulinids; **A**, ammonoids; **Br**, brachiopods; **ST**, sphinctozoans.

A. sphaera (Ozawa), *Cancellina* cf. *C. primigena* Hayden, *C. praeneoschwagerinoides* Leven, *C. phlonghprabensis* Toriyama & Kanmera, *Neoschwagerina simplex tenuis* Toriyama & Kanmera, *N.* aff. *N. simplex* Ozawa, *Praesumatrina schellwieni* (Deprat).

Sphinctozoans. *Colospongia* sp., *Crymocoelia zacharovi* Belyaeva, *Vesicotubularia prima* Belyaeva, *Paradeningeria martaensis* Belyaeva, *Sollasia* sp.

Brachiopods. *Acosarina* sp., *Rugaria molengraaffi* (Broili), *Urushtenia murina* (Grant), *Neoplicatifera* sp., *Comuquia* cf. *C. modesta* Grant, *Marginifera carniolica* (Schellwien), *Transennatia gratiosa* (Waagen), *Bilotina acantha* (Waterhouse & Piyasin), *Linoproductus* aff. *L. kaseti* Grant, *Compressoproductus mongolicus* (Waagen), *Ogbinia dzhagrensis* Sarytcheva, *Uncinunellina siculus* (Gemmellaro), *Anomaloria glomerosa* Grant, *Permophricodothyris caroli* (Gemmellaro), *Martinia ceres* (Gemmellaro).

Ammonoids. *Propinacoceras* sp., *Prostacheoceras tauricum* (Toumansky), *Cardiella kussica* (Toumansky). Apparently, the ammonoids described by Toumansky (1931) also originated from Locality 110/1. These were identified as *Parapronorites konincki* Gemmellaro, *Propinacoceras galilaei* Gemmellaro, *P.? soramanse* Toumansky, *P.? almense* Toumansky, *Medlicottia? volgi* Toumansky, *Thalassoceras karpinskyi* Toumansky, *Agathiceras suessi* Gemmellaro, *A. planum* Toumansky, *A. bodraki* Toumansky, *A. katsche* Toumansky, *A. bachui* Toumansky, *A. anceps* Gemmellaro, *Cardiella kussica* (Toumansky), *Neocrimites* (*Sosiocrimites*) *biassalensis* Toumansky, *Aricoceras* aff. *A. ensifer* (Gemmellaro), *Palermites* cf. *P. distefanoi* (Gemmellaro), *Prostacheoceras multidentatum* (Toumansky), *P. burnense* (Toumansky), *Stacheoceras mediterraneum crimense* Toumansky, *S. andrussowi* Toumansky, *S. bosei* Toumansky, *S. borissiaki* Toumansky, *S. vogti* Toumansky, *S.* cf. *S. tietzei* Gemmellaro, *S. tepense* Toumansky, *Tauroceras wanneri* (Toumansky), *T. serobiculatus martensis* (Toumansky), *Paraceltites hoefori sophiensis* Toumansky.

Trilobites and single fragments of isolated tetracorals belonging to the family Plerophyllidae (most likely to the genera *Pentaphyllum* and *Ufimia*) where noted by Toumansky (1935), who also indicated that small bivalves and gastropods were also present at this locality.

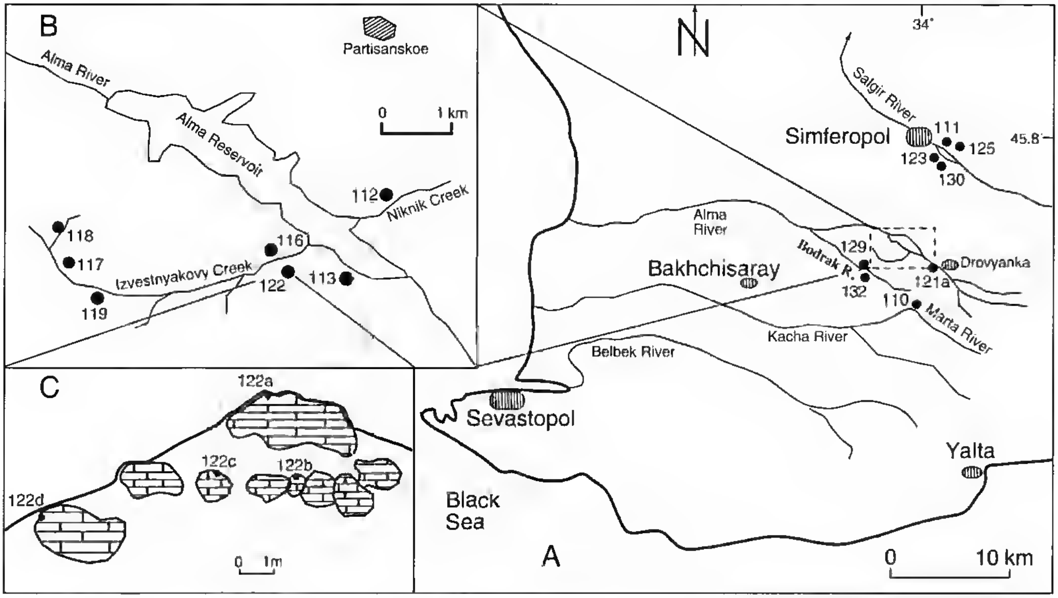

FIG. 4. — **A**, map of the study area with localities of the Permian and Triassic exotic blocks; **B**, location of Permian exotic blocks in the Alma River Basin; **C**, location of the upper Midian (Capitanian) and Dzhulfian limestone blocks on the right side of Izvestnyakovy Creek in the Alma River Basin. Site is on the left side of a trail going up from the Alma Reservoir and is in dense forest.

Loc. 110/sample 4

This sample, located at the northern margin of the block (Fig. 5), consists of medium sorted skeletal grainstone, with *Lithocodium*, coated grains, intraclasts, foraminifers, gastropods and other shell fragments.

Small foraminifers. *Palaeotextularia* sp., *Deckerella* sp. 2, *Climacammina valvulinoides* Lange, *Palaeospiroplectammina* ex gr. *P. conspecta* Reitlinger, *Polytaxis* sp., *Orthovertella* sp., *Neodiscus* aff. *N. milliloides* A. M.-Maclay.

Fusulinids. *Minojapanella* sp., *Parafusulina cincta* Reichel, *P.* cf. *P. erratoseptata* Kling, *P. crassiseptata* Leven, *P.* cf. *P. undulata* Chen, *P. japonica* (Guembel), *P. nakamigawai* Morikawa & Horiguchi, *Pseudofusulina* aff. *P. hisamatsui* Morikawa.

Loc. 110/sample 2

This sample is a reefoidal boundstone with encrusted skeletal elements and cavities filled with biosiltite.

Loc. 110/sample 3

This sample is from a small (about 0.7 m across) block. The limestone consists of a well-sorted skeletal grainstone with intraclasts and with coated grains formed from calcareous sponges, foraminifers, gastropods, brachiopod spines and bryozoans.

Fusulinids. *Neofusulina tumida* (Ozawa), *Yangchienia* cf. *Y. compressa* (Ozawa), *Parafusulina cincta* Reichel, *Armenina sphaera* (Ozawa), *Neoschwagerina simplex* Ozawa, *N. simplex tenuis* Toriyama & Kanmera, *Praesumatrina neoschwagerinoides* (Deprat).

Brachiopods. *Acosarina* sp., *Neoplicatifera* sp., *Transennatia gratiosa* (Waagen), *Uncinunellina* cf. *U. amor* (Gemmellaro).

Loc. 110/samples 6, 7

These samples consist of a poorly sorted calcirudite, with biocalcarenite packstone pebbles, fragments of oncoidal crust, calcareous algae, foraminifers, gastropods, bryozoans, brachiopods and shell fragments. Internal fissures are filled with fine-grained calcarenite. The environment of deposition is interpreted as marine forereef.

Small foraminifers. *Tuberitina collosa* Reitlinger, *Mendipsia conili* (Nguyen Duc Tien), *M.* sp.,

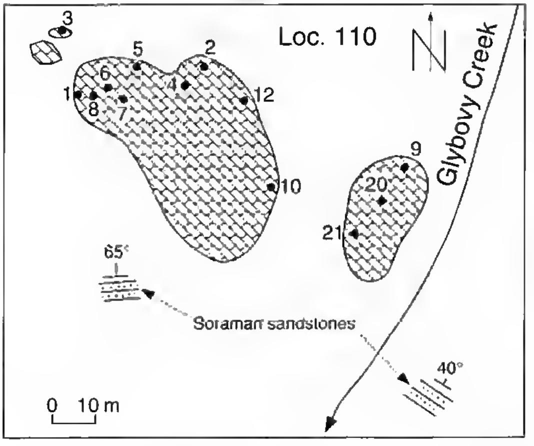

FIG. 5. — Location of collection sites at the Kichkhi-Burnu Permian limestone blocks in the Marta River Basin (Loc. 110). Matrix consists of the Soraman sandstone (Pliensbachian).

Lasiodiscus sp. 1, *Palaeotextularia* sp. (= *P. longiseptata* Lipina *in* Zheng 1986), *Deckerella media permiana* Wang, *Palaeospiroplectammina* ex gr. *P. conspecta* Reitlinger, *Tetrataxis maxima* Schellwien, *T.* sp., *Globivalvulina graeca* Reichel, *Calcivertella* sp., *Orthovertella* sp., *Neodiscus* aff. *N. milliloides* A. M.-Maclay, *Pachyphloia sphaerula* Sosnina, *P. ovata* (Lange), *Nodoinvolutaria jilinica* Han.

Fusulinids. *Neoschwagerina simplex* Ozawa, *Cancellina* sp., *Praesumatrina rossica* A. M.-Maclay, *Neofusulinella nana* A. M.-Maclay.

Loc. 110/sample 5

This sample consists of a poorly sorted biocalcirudite, with calcareous algae, foraminifers, aggregates and encrusting laminated microbial mats (*Sphearocodium*).

Small foraminifers. *Globivalvulina* sp., *Palaeotextulariida* indet.

Fusulinids. *Yangchienia haydeni* Thompson, *Y. tobleri* Thompson, *Parafusulina sapperi* (Staff), *P. japonica* (Gumbel), *P. nakamigawai* Morikawa & Horiguchi, *Pseudofusulina* cf. *P. uenoensis* Kobayashi, *Armenina saraburiensis* Toryama & Kanmera, *Verbeekina verbeeki* (Geinitz), *Cancellina sephaputi* Kanmera & Toriyama, *Neoschwagerina colaniae* Ozawa, *N.* ex gr. *N. pinguis* Skinner, *N. craticulifera* (Schwager), *Pseudodoliolina ozawai* Yabe & Hanzawa, and *Praesumatrina grandis* Leven.

Loc. 110/sample 10

At this locality near the eastern side of the block, the talus is composed of slightly marly gray limestone yielding remains of brachiopods, ammonoids and trilobites.

Brachiopods. *Enteletes* cf. *E. sublaevis* Waagen, *E. geniculatus* Licharew, *Linoproductus* aff. *L. kaseti* Grant, *Ogbinia dzhagrensis* Sarytcheva.

Sphinctozoans. *Colospongia* sp., *Crymocoelia zacharovi* Belyaeva, *Vesicotubularia prima* Belyaeva, *Paradeningeria martaensis* Belyaeva, *Sollasia*? sp.

Ammonoids. *Propinacoceras* sp., *Prostacheoceras tauricum* (Toumansky), *Cardiella kussica* (Toumansky).

Loc. 110/samples 9, 20, 21

Southeast of the main block at this locality there is a smaller block exposed along the Glybovy Creek (Fig. 5). The lithology of the block consists of a poorly sorted calcirudite to calcarenite packstone, with reefboundstone clasts, fragments of oncoidal crust, calcareous algae, foraminifers, crinoids, bryozoans, brachiopods and shell fragments. Internal fissures are filled with micrite. This lithology and fauna indicate a marine forereef palaeoenvironment.

Small foraminifers. *Tuberitina collosa* Reitlinger, *Atjussella* sp., *Mendipsia* sp., *Dagmarita* sp., *Globivalvulina* sp., *Neodiscus* aff. *N. milliloides* A. M.-Maclay.

Fusulinids. *Neofusulinella lantenoisi* Deprat, *N. saraburiensis* Toriyama, Kanmera & Ingevat, *N. nana* A. M.-Maclay, *Armenina salgirica* A. M.-Maclay, *Armenina prisca* Toriyama & Kanmera, *Verbeekina* sp., *Praesumatrina neoschwagerinoides* (Deprat), *Cancellina primigena* Hayden, *C. saraburiensis* Kanmera & Toriyama, *C.* (*Shengella*) *elliptica* Yang, *Neoschwagerina simplex* Ozawa, *Parafusulina granumavenae* (Roemer), *P.* aff. *P. tchuenkovi* Leven, *P.* aff. *P. yabei* Hanzawa, *Chusenella tingi* Sheng.

Brachiopods. *Neoplicatifera* sp., *Marginifera carniolica* (Schellwien), *Rostranteris inflatum* (Gemmellaro).

Limestone of the main body of the Marta block (Loc. 110) is characterised by two assemblages of fusulinids: an assemblage of the *Neoschwagerina*

simplex zone (Loc. 110/1, 3, 4, 9, 20, 21) and the assemblage of the *Neoschwagerina craticulifera* zone (Loc. 110/5). According to Bogoslovskaya (1984), two ammonoid assemblages are recorded in the Marta block: (1) an older one of Roadian (Burnian) age; (2) a younger one of Wordian (Martian) age. Zakharov (this work) found only the Roadian ammonoid assemblage (Loc. 100/1, 10). Small foraminifers (Loc. 110/1, 2, 4, 6, 7, 9, 20, 21) are Roadian or Kubergandian. The brachiopod assemblage (Loc. 110/1-3, 9, 10, 21), is most probably also of a same age. The Roadian ammonoids, small foraminifers and brachiopods occur with fusulinids of the *Neoschwagerina simplex* zone.

ALMA RIVER BASIN

Exotic blocks and pebbles of Permian limestone within Eskiorda Serie are also recorded in the Alma River Basin, in the areas of the Bodrak River, and Izvestnyakovy and Niknik creeks (Fig. 4B).

Loc. 129

Many blocks of different ages have been observed in the Bodrak River area. Here we are describing a new Permian block (Loc. 129) discovered in 1996 (Fig. 4A). This isolated block is located on the right bank of the river near Trudolubovka Village.

The block from which this sample (Loc. 129) was obtained is about 0.5 m across. It is a biocalcirudite with carbonate-quartzitic cement and rounded millimetre to centimetre sized pebble clasts of lime mudstone, calcareous sponges, radiolarian lime mudstone, corals, and foraminifers. There are also single ooids in the matrix. This texture indicates an exposure of a Permian sequence reworked in a high-energy shallow platform marine environment with quartzitic terrigenous input.

Small foraminifers. *Lasiodiscus tenuis* Reichel, *Globivalvulina* sp., *Agathammina* sp., *Nodosaria caucasica mirabilis* K. M.-Maclay, *Pachyphloia cukurkoyi* Civrieux & Dessauvagie.

Loc. 122

On the right bank of Izvestnyakovy Creek, about 350 m upstream from its mouth, several blocks (Loc. 122) of gray and light gray crinoid limestone (about 15 × 6 m) were discovered (Fig. 4C). They contain remains of algae, and sphinctozoans – *Colospongia* cf. *C. salinaria* (Waagen & Wentzel), *Vesicotubularia prima* Belyaeva.

Loc. 122a

This sample consists of a clast-supported calcirudite with encrusted microbial elements and biocalcarenite with foraminifers. Diagenesis showing radiaxal cement and internal filled cavities of silty mudstone indicates an upper shoreface marine depositional environment.

Small foraminifers. *Eotuberitina reitlingerae* A. M.-Maclay, *Mendipsia conili* (Nguyen Duc Tien), *Lasiodiscus tenuis* Reichel, *Lasiotrochus* sp., *Postendothyra* sp., *Climacammina* sp., *Palaeospiroplectammina* sp., *Dagmarita* sp., and *Geinitzina* sp.

Loc. 122b

This sample is a clast-supported calcirudite from a perireefal environment containing foraminifers, calcareous algae, bryozoans and brachiopods.

Small foraminifers. *Eotuberitina reitlingerae* A. M.-Maclay, *Tuberitina collosa* Reitlinger, *Lasiodiscus tenuis* Reichel, *Neoendothyra* sp., *Postendothyra* sp., *Palaeotextularia* sp. 3, *Climacammina* sp. 1, *C. verbeeki* Lange, *C.* ex gr. *C. valvulinoides* Lange, *Deckerella* sp., *Palaeospiroplectammina* sp., *Tetrataxis* sp., *Abadehella* sp., *Agathammina* sp., *Multidiscus* sp., *Nodosaria sagitta* K. M.-Maclay, *N. planocamerata* Sosnina, *Langella perforata langei* Civrieux & Dessauvagie, *Geinitzina araxensis* G. Pronina, *G. spandeli* Tcherdynzev, *G. uralica simplex* K. M.-Maclay, *Pachyphloia robusta* K. M.-Maclay, *Pseudotristix solida* Reitlinger, *Ichtyolaria primitiva* Civrieux & Dessauvagie, and *Hubeirobuloides* sp.

Fusulinids. *Codonofusiella* cf. *C. erki* Rauser, and *Reichelina changhsingensis* Sheng & Chang.

Loc. 122c

This sample is a reefal boundstone with a *Microcodium* type of encrustation and radiaxal cement.

Small foraminifers. *Lasiodiscus minor* Reichel, *Neoendothyra* sp., *Globivalvulina* sp., *Hemigordius* sp., and *Geinitzina* sp.

Fusulinids. *Yangchienia* cf. *Y. thompsoni* Skinner & Wilde, *Chusenella* sp., *Nankinella* cf. *N. ovata* A. M.-Maclay, and *Reichelina cribroseptata* Erk.

Loc. 122d
This sample is a calcirudite of poorly sorted broken clasts in a bioclastic matrix.
Small foraminifers. *Mendipsia conili* (Nguyen Duc Tien), *Tuberitina collosa* Reitlinger, *Lasiodiscus minor* Reichel, *Deckerella* sp., *Endoteba controversa* Vachard & Razgallah, *Dagmarita* sp., *Globivalvulina cyprica* Reichel, *G. vonderschmitti* Reichel, *Postendothyra novizkiana* (Sosnina), *P. micula* (Sosnina), *Neoendothyra ornata* Sosnina, *Tetrataxis conica* Schellwien, *Abadehella* sp., *Orthovertella sphaerica* G. Pronina, *Baisalina pulchra* Reitlinger, *Sphairionia* (*Pseudosphairionia*) *tienii* G. Pronina, *Nodosaria* cf. *N. partisana* Sosnina, *Pseudolangella germosseusis* G. Pronina, *P. filumiformis* G. Pronina, *P. dzhagadzurensis* G. Pronina, *Rectoglandulina gerkei* Sosnina, *Pachyphloia rimula* Sosnina, *P. cukurkoyi* Civrieux & Dessauvagie, *P. minutissima* Sosnina, *Partisania* sp. 1, and *Rectostipulina* sp.
Fusulinids. *Rauserella* sp., *Reichelina cribroseptata* Erk, *Dunbarula nana* Kochansky-Devide & Ramovs, *Lantchichites* cf. *L. minimus* Chen, *Codonofusiella* cf. *C. kueichowensis* Sheng, *Yangchienia thompsoni* Skinner & Wilde, *Chusenella* cf. *Ch. splendens* (Skinner), *Ch.* cf. *Ch. cyri* (Skinner), *Kahlerina pachytheca* Kochansky-Devide & Ramovs, *Verbeekina* cf. *V. furnishi* Skinner & Wilde, *Neoschwagerina schuberti* Kochansky-Devide, *N. haydeni* Dutkevich & Khabakov, *N. kojensis* Toumansky.

Loc. 113
On the left bank of Izvestnyakovy Creek about 550 m upstream from the mouth (Fig. 2B), we found a small block (40 cm × 80 cm) of gray microcrystalline limestone.
Loc. 113 is a calcirudite with ooid grainstone and with biowackestone clasts. The skeletal elements consist of sponges, shell fragments and foraminifers.
Small foraminifers. *Deckerella* aff. *D. elegans* Morozova, *Climacammina valvulinoides* Lange, *Endoteba controversa* Vachard & Razgallah, *Postendothyra guangxiensis* (Lin), *Abadehella* cf. *A. coniformis* Okimura & Ishii, *Globivalvulina graeca* Reichel, *G. vonderschmitti* Reichel, *Agathammina* ex gr. *A. rosella* G. Pronina, *Midiella zaninettiae* (Altiner), *Multidiscus* sp. 1; *M.* sp. 2, *Calcitornella* sp. 2, *Nodosaria* cf. *N. globocularis* Sosnina, *N. dorachamensis* G. Pronina, *N. mirabilis caucasica* K. M.-Maclay, *Pachyphloia* ex gr. *P. pigmobesa* Wang, *P. paraovata* K. M.-Maclay, *P. angulata* K. M.-Maclay, *Pseudotristix* sp., *Geinitzina* sp., *Colaniella* ex gr. *C. minima* Wang, and *C.* ex gr. *C. lepida* Wang.
Fusulinids. *Minojapanella*? sp., *Pseudodunbarula minima* (Sheng & Chang), *P.* aff. *P. arpaensis* Chedija, *Paradunbarula dallyi* Skinner, and *Reichelina changhsingensis* Sheng & Chang.

Loc. 112
On the opposite side of the Alma River Valley (Fig. 4B) along Niknik Creek (Loc. 112), gray fine-grained sandstone crops out which contains an isolated block (about 3 m across) of gray brecciated limestone with "boulder" jointing with ammonoid remains.
Ammonoids. *Propinacoceras* sp., *P.* sp. indet., *Agathiceras* sp., *A.* sp. indet., *Cardiella kussica* (Toumansky), *Adrianites*? sp., *Tauroceras* sp., *Paraceltites*? sp. This assemblage is Roadian or Kubergandian age.

Simferopol area
The geology of the Simferopol area is described in Moiseev (1937). During this study the exotic blocks were examined at Cape Dzhien-Safu, near Marjino Village, and east of Simferopol Reservoir (Fig. 6A).

Loc. 111
On the western end of Cape Dzhien-Safu at Simferopol Reservoir (Loc. 111) there is a large, northwest trending, elongate block of limestone (Fig. 6). It is about 180 m along the long axis. On the marginal parts, it is composed of black and dark gray microcrystalline limestone which is massive, fissured, and contains pockets of accumulations of fusulinid shells (Loc. 111/1).

Loc. 111/sample 1
Fusulinids. *Parafusulina crassispira* Leven, *P.* aff.

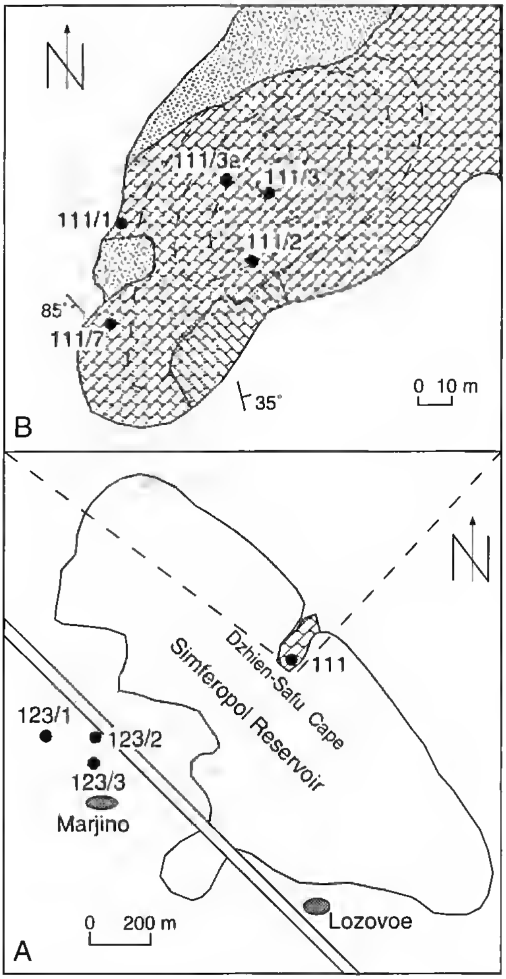

FIG. 6. — **A**, location of the Permian limestone block (Cape Dzhien-Safu) and pebbles (Marjino Village) near the Simferopol Reservoir; **B**, collection sites at the lower Midian (Wordian) limestone block (Loc. 111) in the western part of Cape Dzhien-Safu.

P. dronovi Leven, *Chusenella* sp., *Eopolydiexodina* aff. *E. zulumartensis* Leven, *Armenina salgirica* A. M.-Maclay, *Verbeekina verbeeki* (Geinitz), *Cancellina praeneoschwagerinoides* Leven, *C. cutalensis* Leven, *C. tenuitesta* Kanmera, *Neoschwagerina simplex* Ozawa, *Praesumatrina rossica* A. M.-Maclay, *Pseudodoliolina ozawai* Yabe & Hanzawa. The age is Kubergandian.

Loc. 111/sample 7

Small foraminifers. *Tuberitina collosa* Reitlinger, *Mendipsia conili* (Nguyen Duc Tien), *Globivalvulina vonderschmitti* Reichel, *Postendothyra* sp., *Tetrataxis* ex gr. *T. linea* Ozawa, and *Abadehella* sp.

Fusulinids. *Sumatrina* sp., *Rauserella* sp., and *Cancellina* cf. *C. primigena* (Hayden). The age is early Midian.

Loc. 111/samples 2, 3, 3a

These samples consist of dense biocalcarenite packstone with foraminifers and intraclasts, and are interpreted to be deposited in a marine inner shelf environment.

Small foraminifers. *Eotuberitina reitlingerae* A. M.-Maclay, *Tuberitina collosa* Reitlinger, *Mendipsia conili* (Nguyen Duc Tien), *M.* sp., *Tetrataxis maxima* Schellwien, *T. scita* Lin, *T. linea* Ozawa, *Abadehella hunanensis* (Lin), *Globivalvulina vonderschmitti* Reichel, *G.* aff. *G. permiana* Tcherdynzev, *Postendothyra navizkiana* (Sosnina), *P. ussurica* (Sosnina), *Calcivertella* sp.

Fusulinids. *Afghanella* cf. *A. sumatrinaeformis* (Gubler), *Sumatrina rossica* A. M.-Maclay, *Kahlerina* sp., and *Rauserella* sp. The age is early Midian.

Loc. 123

At Marjino Village (Loc. 123), several small blocks of fossiliferous limestone were found (near the foundation of a house under construction and not available for future study) among coarse-grained Liassic tuffogenic sandstone and conglomerate (Fig. 6A). These samples consist of calcareous quartzitic sandstone with foraminifers.

Loc. 123/sample 2

Fusulinids. *Chusenella deprati* Ozawa, *N.* cf. *N. kojensis* Toumansky, *N. pinguis* Skinner, *N.* aff. *N. minoensis* Deprat, *Colania* aff. *C. akasakensis* (Morikawa & Suzuki), *Yabeina opima* Skinner, *Y. archaica* Dutkevich, *Y.* cf. *Y. globosa* Yabe, *Y. orbiculata* Chedija, *Y. inouyei* Deprat, and *Neoschwagerina craticulifera* (Schwager). This assemblage is of late Midian age.

Loc. 123/sample 3

Northwards, at the margin of the village on the hill slope, we found a separate limestone block measuring about 0.5 × 0.5 m (Fig. 6A).

Fusulinids. *Neofusulinella saraburiensis* Toriyama, Kanmera & Ingevat, *Misellina aliciae* (Deprat), *M. otakiensis* (Huzimoto), *M.* aff. *M. termieri* (Deprat), and *M. claudiae* (Deprat). This assemblage is of Bolorian age.

Loc. 125

Along the eastern side of Simferopol Reservoir (Loc. 125), two limestone blocks were found on the watershed (Fig. 2A). The first one is about 0.8 × 0.5 m, and the second one about 0.5 × 0.5 m. Based of the fusulinid data, the age of limestone from locality 125 is Kubergandian.

Loc. 125/sample 1

This block is composed of dark gray, almost black microcrystalline limestone. The microfacies consists of a mud-supported biocalcarenite rich in foraminifers.

Small foraminifers. *Tuberitina collosa* Reitlinger, *Atjussella grandis* G. Pronina, *Diplosphaerina* aff. *D. maljavkini* (Mikhalov), *Mendipsia* sp., *Endothyra sauera* (Lin), *Globivalvulina graeca* Reichel, *Palaeospiroplectammina* ex gr. *P. conspecta* Reitlinger, *Calcitornella* sp. 1, *Calcivertella* sp., *Agathammina* sp., *Neodiscus* aff. *N. milliloides* A. M.-Maclay, *Nodosaria* sp. (= *N. longissima* Suleimanov *in* Zheng 1986), *Pachyphloia ovata* (Lange).

Fusulinids. *Yangchienia* cf. *Y. compressa* (Ozawa), *Dunbarula*? cf. *D. cascadensis* (Thompson, Wheeler & Danner), *Chusenella schwagerinaeformis* Sheng, *Armenina* aff. *A. prisca* Toriyama & Kanmera, *A. sphaera* (Ozawa), *A. saraburiensis* Toriyama & Kanmera, *Misellina ovalis* (Deprat), *M.* aff. *M. confragaspira* Leven, *M. termieri pamirensis* (Dutkevich), *M. claudiae* (Deprat), *Cancellina primigena* (Hayden), *C.* aff. *C. praeneoschwagerinoides* Leven, *C. dutkevitchi* Leven, *C. cutalensis* Leven, *C. pamirica* Leven, and *Praesumatrina neoschwagerinoides* (Deprat).

Loc. 125/sample 2

Fusulinids. *Yangchienia* sp., *Sichotenella*? sp., *Neofusulinella lantenoisi* Deprat, *Dunbarula*? sp., *Chusenella chihsiaensis* (Lee), *Armenina asiatica* Leven, *Cancellina dutkevitchi* Leven, *C. cutalensis* Leven, *C. zarodensis* Sosnina, *C. sphaera* A. M.-Maclay, *C. verae* (Toumansky), *C.* aff. *C. nipponica* (Ozawa), *Neoschwagerina simplex tenuis* Toriyama & Kanmera, and *Praesumatrina neoschwagerinoides* (Deprat).

ANALYSIS OF FAUNAL ASSEMBLAGES

Ammonoids

The Early Permian (probably, Bolorian) and the Late Permian (Kubergandian or Roadian) (Loc. 110/1, 10) age of the Crimea limestone blocks is established based on the ammonoid data. As was correctly noted by Toumansky (1931, 1937a, 1963), the oldest ammonoids of the Crimea blocks are forms of the Soramanian assemblage, that she discovered in one of dark gray limestone blocks of Kichik-Soraman Mountain. This assemblage is comprised of representatives of *Propinacoceras*, *Sicanites*, *Agathiceras*, *Gastrioceratac͏eae*, *Almites*?, *Cardiella*, and *Crimites*. The Early Permian age of the assemblage is confirmed by the presence of representatives of *Crimites-C, gemmellaroi*, *C. hanieli*, *C.* sp. indet., and apparently *Almites-A.*? *pigueum*. Species of the genus *Cardiella* are not found in deposits older than Bolorian. Therefore, it would be most logical to assume that the limestone blocks containing these ammonoids belong to the Bolorian stage of the Lower Permian.

The generic composition of ammonoids from limestone blocks on the right side of one of the tributaries of the Marta River in the area of Kichkhi-Burnu Mountain [*Parapronorites*, *Propinacoceras*, *Medlicottia*?, *Thalassoceras*, *Agathiceras*, *Cardiella*, *Neocrimites* (*Sosiocrimites*), *Aricoceras*, *Palermites*, *Prostacheoceras*, *Tauroceras*, and *Paraceltites*] (with respect to our new evidence) is almost identical to the Kubergandian assemblage, that confirms the relevant conclusion initially drawn by Toumansky (1963). Noting the similarity of this assemblage with ammonoids from limestone of the Sosio Permian blocks, Toumansky (1963) correctly noted the absence of reliable representatives of *Waagenoceras* as well as *Hyattoceras*, *Doryceras*, *Clinolobus*, *Epiglyphioceras* (all known from Sicily). This list can be extended by the following genera: *Aristoceratoides*, *Altudoceras*, *Hoffmannia*, and *Sizilites*. Most of these genera are also not found in the stratotype of Kubergandian stage.

We assume that the light grey limestone of Kichkhi-Burnu Mountain is of Kubergandian age [forms from the Kubergandian deposits of Southeastern Pamirs defined by Toumansky (1935) and Bogoslovskaya (Chedija *et al.* 1986) as *Popanoceras* are assigned to the genus *Tauroceras* in the present paper]. Grey limestone on the right-bank of the Alma River (Niknik Creek) yielding *Propinacoceras*, *Agathiceras*, *Cardiella*, *Adrianites*, *Stacheoceras*, and *Paraceltites*? is apparently of Kubergandian age.

Small foraminifers

Analysis of the Permian small foraminifers shows that there are five assemblages of different ages. The oldest assemblage is found in two localities: in the Marta River Basin (Loc. 110/1, 2, 4, 6, 7, 9, 20, 21), and on the eastern flank of the Simferopol Reservoir (Loc. 125/1; Figs 4A, 5). The most typical species of the assemblage are *Neodiscus* aff. *N. milliloides* A. M.-Maclay and *Nodoinvolutaria jilinica* Han. The first occurs in the lower part of the Gnishik Formation (the *Neodiscus milliloides* zone) of Transcaucasia (Pronina 1990), and in the Qixia Group (*Eolasiodiscus-Neodiscus maopingensis* zone) of Daxiakou, Xingshan County, Hubei Province, China (Zheng 1986). However, it has been identified there as *Neodiscus maopingensis* Wang & Sun and *Glomospira duplicata* Lipina. *Nodoinvolutaria jilinica* Han has been known previously from the Miaoling Formation of northeastern China, that belongs to the *Neoschwagerina* zone (Han 1982). In addition to *Neodiscus* aff. *N. milliloides* A. M.-Maclay, the following species are in common within the Qixia Group – *Palaeotextularia pingguoensis* Lin, *P.* sp. (= *P. longiseptata* Lipina) and *Endothyra saucra* (Lin) (Zheng 1986). The presence of *Neodiscus* aff. *N. milliloides* A. M.-Maclay in this assemblage, a zonal species and index of the same named zone of Transcaucasia, permits us to correlate the assemblage of small foraminifers from Loc. 110 (except Loc. 110/5) and Loc. 125/1 to the *Neodiscus milliloides* zone of Transcaucasia, and to the *Eolasiodiscus-Neodiscus maopingensis* zone of Hubei Province of China. The last zone is correlated to the small foraminifer *Pseudovidalina delicata-Langella-Neodiscus maopingensis* zone and the fusulinid *Neoschwagerina simplex-Cancellina neoschwagerinoides* zone of the Xiangboan Stage of China (Sheng & Jin 1994), that correspond to the Kubergandian stage of the Tethyan scale or the Roadian of the stand-ard scale.

The second assemblage of small foraminifers has been recognised in the limestone of Cape Dzhien-Safu, Simferopol Reservoir (Loc. 111/2, 3, 7; Fig. 6B). Among the numerous foraminifers present, the following species are diagnostic – *Tetrataxis scita* Lin, *T. linea* Ozawa, *Abadehella hunanensis* (Lin), *Globivalvulina vonderschmitti* Reichel, *G.* aff. *G. permiana* Tcherdynzev, *Postendothyra novizkiana* (Sosnina), and *P. ussurica* (Sosnina). All species of this association occur in the Arpa Formation of Transcaucasia (Kotlyar *et al.* 1989). In addition, *Abadehella hunanensis* (Lin) and *Tetrataxis scita* Lin are known from the Douling Formation of the Chinese Province of Hubei and correlated with the upper part of the Maokou Formation of China (Lin 1985). Thus, the assemblage of small foraminifers from Cape Dzhien-Safu is considered to be early Midian of the Tethyan scale or late Wordian of the standard scale.

The third assemblage of small foraminifers was found in the limestone block on the right side of Izvestnyakovy Creek in the Alma River Basin at Loc. 122d (Fig. 4C). This assemblage contains a mixed fauna which occurs in the Arpa Formation [species: *Sphairionia* (*Pseudosphairionia*) *tienii* G. Pronina, *Pseudolangella geranossensis* G. Pronina, *P. dzhagadzurensis* G. Pronina, and *P. filumiformis* G. Pronina], and in the Khachik Formation (species: *Deckerella* sp. 1, *Globivalvulina cyprica* Reichel, *G. vonderschmitti* Reichel, *Orthovertella sphaerica* G. Pronina, *Baisalina pulchra* Reitlinger, *Septagathammina* sp., *Rectoglandulina gerkei* Sosnina, *Pachyphloia rimula* Sosnina, and *Partisania* sp. 1) of Transcaucasia (Kotlyar *et al.* 1989; Pronina 1990). The age of the association from Loc. 122d is most likely late Midian of the Tethyan scale or Capitanian of the standard scale. The early Midian species are probably reworked.

The fourth assemblage of small foraminifers was found in the limestone block at locality 122b (Fig. 4C). This association is represented by species occurring in the uppermost Khachik and Dzhulfa formations, and in the lower part of the Akhura Formation of Transcaucasia (Kotlyar *et al.* 1989; Pronina 1990). Therefore, the age of this assemblage is considered to be Dzhulfian.

The fifth and the youngest association of small foraminifers has been found in a limestone block from Izvestnyakovy Creek in the Alma River Basin (Loc. 113; Fig. 4B). This assemblage contains a mixed fauna, that occurs in the uppermost Khachik and Dzhulfa formations and the lower part of the Akhura Formation (*Deckerella* aff. *D. elegans* Morozova, *Nodosaria mirabilis caucasica* K. M.-Maclay, *Agathammina* ex gr. *A. rosella* G. Pronina, and *Multidiscus* sp. 1), and in the Dorasham and the upper part of the Akhura Formations [*Postendothyra guangxiensis* (Lin), *Nodosaria dorachamensis* G. Pronina, *Pachyphloia paraovata* K. M.-Maclay, *P.* ex gr. *P. pigmobesa* Wang, *Pseudolangella dorachamensis* G. Pronina, *Colaniella* ex gr. *C. minima* Wang, and *C.* ex gr. *C. lepida* Wang] of Transcaucasia (Pronina 1990). Therefore, it is impossible to establish the exact age, but most likely, this assemblage is Dorashamian (Changsingian), and the Dzhulfian species are reworked.

Fusulinids

Fusulinids from the Crimea Permian exotic blocks have been studied by various workers (Toumansky 1941; Einor & Vdovenko 1959; Miklukho-Maklay 1963), and they have been correlated to various stratigraphical levels of Early Permian to Late Permian age. Davydov (1991) investigated fusulinids from 13 exotic blocks and numerous limestone pebbles. He recognized the following biostratigraphic levels: (1) *Misellina alicia*, *M. claudiae* of upper Bolorian age (Loc. 123/3); (2) *Cancellina cutalensis* of Kubergandian age (Loc. 125); (3) *Praesumatrina*, *Neoschwagerina simplex* (Loc. 110/1, 3, 4, 9, Loc. 111/1) of Lower Murgabian age; (4) *Neoschwagerina craticulifera*, *Afghanella*, *Sumatrina* of Murgabian age (Loc. 110/5); (5) *Neoschwagerina margaritae* of Midian age (Loc. 110/1a); (6) *Yabeina opima* of Midian age (Loc. 123/2); (7) *Pseudodunbarula minima*, *Paradunbarula dallyi* of Dzhulfian age (Loc. 113). According to Davydov (1991), the Crimea fusulinid succession ranging from Bolorian (Kungurian) to Late Permian (Dzhulfian) are typical Tethyan assemblages and are very similar to the fusulinid faunas from Elburz, Iran (Lys *et al.* 1978). The fusulinids from several Crimean exotic blocks (Loc. 110/20, 21, Loc. 122a-d) have been studied recently by Nestell (Pronina & Nestell 1997).

Six fusulinid assemblages appear to be present in the Crimean blocks.

The first assemblage occurs in a small limestone block at the margin of the Marjino Village within Simferopol area (Loc. 123/3). The most important forms are: *Misellina claudiae* (Deprat), *M. aliciae* (Deprat), *M. otakiensis* (Fujimoto), *M.* aff. *M. ermieri* (Deprat). According to Davydov (1991) and Leven (1980) these species are most characteristic for late Bolorian.

The second one is the most diverse and abundant. It occurs in the largest limestone block exposed in Marta River Basin (Loc. 110, except Loc. 110/5), and in a small block on the eastern side of the Simferopol Reservoir (Loc. 125/1, 2, Loc. 111/1). The most important and typical species of this assemblage are: *Neoschwagerina simplex* Ozawa, *Cancellina* (*Shengella*) *elliptica* Yang, *Cancellina* sp., *Praesumatrina neoschwagerinoides* (Deprat), *Chusenella schwageriniformis* Sheng, *Ch. chihsiaensis* (Lee), *Parafusulina* sp., and *Eopolydiexodina* sp. This assemblage belongs to the *Neoschwagerina simplex*-*Cancellina neoschwagerinoides* zone of the Xiangboan Stage of China (Sheng & Jin 1994). The age is most likely late Kubergandian.

The third assemblage occurs on the top of the largest limestone block from the Kichkhi-Burnu Mountain (Loc. 110/5). With the exception of some older reworking species such as *Armenina saraburiensis* Toriyama & Kanmera, *Cancellina sethaputi* Kanmera & Toriyama and others, this

assemblage contains the typical Murgabian and even early Midian forms. Among them are *Verbeekina verbeeki* (Geïnitz), *Neoschwagerina craticulifera* (Schwager), *N. colaniae* Ozawa, *N.* ex gr. *N. pinguis* Skinner, *Afganella schenki* Thompson, *Sumatrina* sp. Therefore, the age of this assemblage is considered to be Murgabian.

The fourth assemblage occurs in a limestone block at Cape Dzhien-Safu, Simferopol Reservoir (Loc. 111/2, 3, 3a). The most characteristic species are *Eopolydiexodina* sp., *Afghanella* cf. *A. sumatrinaeformis* (Gubler), *A.* sp., *Sumatrina rossica* A. M.-Maclay, *S. longissima* Deprat, *S. brevis* Leven, and *Kahlerina* sp. These species are early Midian in age in spite of the presence of older taxa (*Neoschwagerina simplex*, *Verbeekina*, *Armenina*). There is possibly some reworking of older forms in this block. However, there is clearly a definite internal stratigraphic succession present in parts of this block and until closely spaced samples are studied, the precise age of the block is not clear.

The fifth assemblage has been recognised in the limestone block on the right bank of Izvestnyakovy Creek in the Alma River Basin (Loc. 122d). The assemblage consists of mixed early Midian (late Wordian) and late Midian (Capitanian) species. Most likely, the age is late Midian or Capitanian. A late Midian (Capitanian) assemblage also has been found in small pebbles near Marjino Village (Loc. 123/2). Present in these pebbles are *Neoschwagerina craticulifera* (Schwager), *N.* cf. *N. kojensis* Toumansky, *N. pinguis* Skinner, *Yabeina opima* Skinner, *Y.* cf. *Y. globosa* Yabe, and *Y. orbiculata* Chedija.
The sixth fusulinid assemblage is from the limestone block at localities 122b and 113. It is probably Dzhulfian is age and contains *Codonofusiella* cf. *C. erki* Rauser and *Reichelina changhsingensis* Sheng & Chang.

Brachiopods
Permian brachiopods are confined to the largesr limestone block in the Marta River Basin that is named Kichkhi-Burnu Mountain (Fig. 5). The analysis of brachiopod associations from separate parts of this block permits two assemblages to be distinguished.
The oldest and most representative assemblage is characteristic of most of the Marta River block (Loc. 110/1-3, 7, 9, 10, 21). These assemblages are characterised by a predominance of Bolorian-Kubergandian species. *Rugaria molengraaffi* (Broili), *Urushtenia murina* (Grant), *Comuquia modesta* Grant, *Transennatia gratiosa* (Waagen), *Bilotina acantha* (Waterhouse & Piyasin), *Linoproductus kaseti* Grant, *Anomaloria glomerosa* Grant, *Phricodothyris asiatica* (Chao) occur in the Rat Buri Limestone of Thailand (Grant 1976). *Rugaria molengraaffi* (Broili) is described from the Bitauni block of Timor (Broili 1915), *Enteletes geniculatus* Licharew, *Echinoconchus fasciatus* (Kutorga), *Phricodothyris asiatica* (Chao), *Hemiptychina darvasica* Tschernyschew are known from Bolorian-Kubergandian deposits of the Darvaz, *Echinoconchus fasciatus* (Kutorga) and *Marginifera carniolica* (Schellwien) – from the Trogkofel Limestone of the Carnic Alps and Karawanken (Schellwien 1900). A number of species have also been described from Murgabian and Midian deposits in some regions of the Tethys. *Ogbinia dzhagrensis* Sarytcheva is known from the Gnishik Formation of Transcaucasia (*Neoschwagerina simplex* and *N. craticulifera* zones), and *Enteletes sublaevis* Waagen is from the Wargal Formation in Salt Range of Pakistan, *Martinia ceres* (Gemmellaro), *Rostranteris inflatum* (Gemmellaro) is from the Sosio Permian blocks of Italy. However, these species are also frequently recorded in deposits older than Murgabian and Midian. This assemblage occurs with the small foraminifers and fusulinids of the *Neoschwagerina simplex-Cancellina neoschwagerinoides* zone, that is attributed to the Chihsian Series (Sheng & Jin 1994) and with Kubergandian (Roadian) ammonoids. So, the age brachiopod assemblage from the abovementioned localities is most likely late Kubergandian.

The second assemblage occurs only at the top of Kichkhi-Burnu Mountain (Loc. 110/8). It is extremely scarce and is represented only by a few species – *Ogbinia dzhagrensis* Sarytcheva, *Transennatia gratiosa* (Waagen), *Uncinunellina* cf.

U. amor (Gemmellaro), and *Permophricodothyris pulcherrima* (Gemmellaro). All of the species are characteristic of Murgabian and lower Midian (or Upper Wordian) deposits in the Tethyan Realm, although they also occur in older formations.

However, it should be added that previously other Midian and younger species have been reported from the Marta River block. Species of Dorashamian age, such as *Geyerella tschernyschewi* Licharew, "*Plicatifera*" cf. "*P.*" *bajarunassi* Licharew, *Richthofenia caucasica* Licharew, *Leptodus richthofeni* Kayser, *Camarophoria paronae* Gemmellaro, and *Jisuina nikitini* Gemmellaro, have been reported (Einor & Vdovenko 1959; Licharew 1966). Therefore, within Kichkhi-Burnu Mountain there are probably blocks of various ages, even of younger age than Midian.

Sphinctozoans

Permian sphinctozoans of the Crimea are represented by five genera – *Colospongia* Laube, *Crymocoelia* Belyaeva, *Vesicotubularia* Belyaeva, *Paradeningeria* Senowbary-Daryan & Schafer, 1979 and, *Sollasia* Steinmann, 1882. Representatives of *Colospongia* are wide-spread in Upper Carboniferous-Upper Triassic deposits of the former USSR. Species of this genus occurring in the Crimea are very similar in the shape of chambers, character of their function, size and abundance of vesicles to *C. salinaria* (Waagen & Wentzel) known from the Upper Permian of China and India, as well as from the Upper Triassic of North America, and the European Alps.

The species *Crymocoelia zacharovi* Belyaeva, the type species of the recently established genus, was described from the Permian of the Crimea, and representatives of the genus are as yet unknown from other places. The nature of the porosity of the catenulate branches of this retrosiphonate type allows the Crimean form to be assigned to the family Sebargasiidae. Within this family, these forms are most similar to *Amblysiphonella* Steinmann, 1882. That genus is the most abundant among fossil sphinctozoans from a systematic viewpoint and its age ranges from the Ordovician to the Upper Triassic. However, *Crymocoelia*, unlike closely similar forms, is noted for a complex porosity of the siphon wall, that is very rare for sphinctozoans.

Vesicotubularia prima Belyaeva was also first described from the Crimea and is similar to the previous genus. These forms are very peculiar sphinctozoans, where an important part of the skeletal structure is their vesicular (bubble) tissue. Representatives of the genus *Vesicocaulis*, particularly *V. alpinus* Ott from the Upper Triassic of the Alps is noted for an aporate character. Such taxa are most closely related to the described Crimean form in their shape and skeletal structure. Representatives of the genus *Vesicocaulis* are known only from Triassic deposits of the Alps, Pamirs and a few other regions.

Until recently, the genus *Paradeningeria* was known only from the Upper Triassic of the Pamirs, Alps, Himalayas, and North America. Permian representatives of *Paradeningeria* in the Crimea belong to the recently established species, *P. martaensis* Belyaeva. Species of the genus *Sollasia* are prevalent in the Upper Permian of Cambodia, Tunisia, Sicily, Venezuela, Texas, and the Far East part of Asia. Isolated occurrences are known in the Triassic of the North Caucasus and the Far East.

Generally, the collection of sphinctozoans from the Permian of the Crimea is rather small and, thus, is probably poor in terms of its systematic composition. The taxa, *Crymocoelia zacharovi* and *Vesicotubularia prima*, are not diagnostic for determining the age of investigated blocks. As far as the other taxa are concerned, *Colospongia* cf. *C. salinaria*, representatives of the genera *Paradeningeria* and *Sollasia* have a wide age distribution from Late Permian to Late Triassic.

Summary of the Permian

1. Study of Crimean Permian exotic limestone blocks demonstrates that carbonate sedimentation from the late Bolorian to practically the end of the Permian occurred in the basin from which these blocks were derived. A depositional environment on a shallow carbonate shelf is indicated for these limestone blocks are predominantly reefogenic.

2. The analysis of all faunal groups from the

Permian exotic blocks and pebbles shows that they contain rich assemblages of primarily small foraminifers and fusulinids. Brachiopods, ammonoids, trilobites, and sphinctozoans are minor constituents of these assemblages.

3. The distribution of fossils points not only to different ages for the various isolated blocks, but also in certain blocks to different ages of various parts of the same block. Sometimes an internal stratigraphic structure is evident in the larger blocks, for example, at the large block at Dzhien-Safu. Mixing of zonal species is often observed, that interferes with precise age determination, even to stage level (Loc. 122).

4. The taxonomic composition of all studied groups definitely points to the Tethyan composition of the faunas. Almost all zonal assemblages of the Bolorian, Kubergandian, Murgabian, Midian, as well as of the Dzhulfian and Dorashamian are present. Fusulinid associations display the greatest similarity to the Elburz assemblages of northern Iran (Davydov 1991). Small foraminifers are comparable with those found in similar age sediments in China, the Far East and Transcaucasia. The brachiopods are like those from Sicily, Thailand and Iran, and ammonoids are comparable with Sicily and Central Asia assemblages.

5. A new Permian small block was discovered on the right bank of the Bodrak River with a small foraminifers fauna. The age of the assemblage from this block is most likely Dzhulfian or Dorashamian (Changsingian).

6. New data concerning the stage to which the *Neoschwagerina simplex-Praesumatrina neoschwagerinoides* zone belongs is most important. Ammonoids found together with a fusulinid assemblage of this zone are clearly Kubergandian or Roadian, according to Zakharov. A Kubergandian (Roadian) age is also confirmed by the small foraminifers of the *Neoschwagerina simplex* zone and, to a certain extent, by brachiopods whose assemblage is dominated by Bolorian and Kubergandian species. This data of the conclusion fully confirms previous researchers concerning assignment of the *Neoschwagerina simplex-Praesumatrina neoschwagerinoides* zone to the Kubergandian (Sheng & Jin 1994; Kotlyar & Pronina 1995).

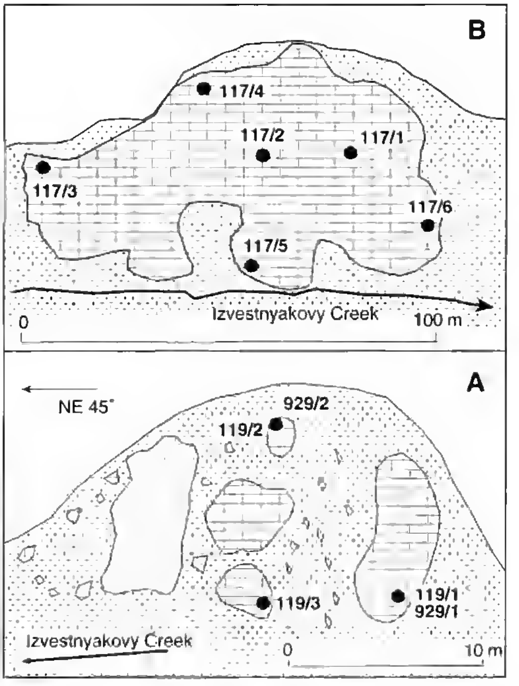

Fig. 7. — Locations of collection sites at the Triassic exotic blocks along Izvestnyakovy Creek in the Alma River Basin; **A**, locality 117; **B**, locality 119. Matrix consists of the deposits of the Mender subunit (Eskiorda Complex).

TRIASSIC EXOTIC BLOCKS

Alma River basin

Triassic limestone blocks occur mainly in the area of Izvestnyakovy Creek and in the Bodrak River area in the Alma River Basin (Fig. 4B). On Izvestnyakovy Creek (Fig. 4B) there are four localities (Locs 116-119) from which Pronina & Vuks (1996) have described the foraminifera. In the Bodrak River at Shvanov Ravine (Loc. 132), a brachiopod assemblage has been determined by Dagis (Dagis & Shvanov 1965).

Loc. 116

This locality crops out on the left bank of Izvestnyakovy Creek about 750 m from its mouth. There are blocks of grey and light gray micritic limestone in size up to 4.5 m across. The main block is a calcilutite wackestone containing small fragments of echinoids and crinoids. Other elements are foraminifers and brachiopods.

Foraminifers. *Tolypammina irregularis* (Salaj, Borza & Samuel), *Pilamminella gemerica* (Salaj), *Gaudryina triadica* Kristan-Tollmann, *Malayspirina* ex gr. *M. alpina* (Zaninetti & Broennimann), "*Calcitornella*" *gebzeensis* Dager, *Coronipora etrusca* (Pirini), *Semiinvoluta bicarinata* Blau, *S. clari* Kristan, *Lamelliconus turris* (Frentzen), *Arenovidalina chialingchiangensis* Ho, *Ophthalmidium lucidum* (Trifonova), *O. triadicum* (Kristan), *Sigmoilina bystrickyi* Salaj, Borza & Samuel, *Nodosaria* cf. *N. dipartita* Kristan-Tollmann, *N.* sp. 1, *Pseudonodosaria* cf. *P. vulgata multicamerata* (Kristan-Tollmann), *Pachyphloides*? sp., *Austrocolomia canaliculata* (Kristan-Tollmann), *Dentalina zlambachensis* Kristan, *Lenticulina rectangula* Kristan-Tollmann, *Duostomina* sp.
Brachiopods. *Euxinella anatolica* (Bittner), *Laballa suessi* (Winkler), *L. slavini* Dagys, *Sinucosta emmrichi* (Suess), *Zugmayerella koessenensis* (Zugmayer), *Oxycolpella oxycolpos* (Emmrich), *Neoretzia superbescens* (Bittner), *Amphiclina intermedia* Bittner, *A. taurica* Moiseev, *Rhaetina turcica* (Bittner), *Triadithyris gregariaformis* (Zugmayer), *Zeilleria bukowski* (Bittner), *Aulacothyropsis almensis* (Moiseev).

Loc. 117 (Fig. 7B)
This is a giant limestone block (100 m × 60 m), occuring on the left bank of Izvestnyakovy Creek about 1.5 km upstream from Loc. 116, and showing an inhomogeneous texture. Due to the nonstratified aspect of the block, the general micritic matrix pink colored in some part, and the presence of numerous cavities with geopetal calcitic cement, we consider that this block is part of a mudmound. Three sampled sites have been analysed from this block.

Loc. 117/sample 1
Foraminifers. *Tolypammina irregularis* (Salaj, Borza & Samuel), *T. gregaria* Wendt, *Spiroplectammina spiralis* Salaj, Borza & Samuel, *Trochammina almtalensis* Koehn-Zaninetti, *Duotaxis inflatus* (Kristan-Tollmann), *Textularia* ex gr. *T. exigua* (Schwager), *Endoteba kuepperi* (Oberhauser), *Malayspirina* sp., *Meandrospirella*? sp., *Semiinvoluta bicarinata* Blau, *S. clari* Kristan, *Arenovidalina chialingchiangensis* Ho, *Nodosaria simplex* (Terquem), "*Frondicularia woodwardi*" Howchin, *Austrocolomia* sp., *Lenticulina goettingensis polygonata* (Franke), *Diplotremina astrofimbriata* Kristan-Tollmann, *Duostomina* sp.
Brachiopods. *Euxinella anatolica* (Bittner), *Crurirhynchia kiparisovae* Dagys, *Laballa slavini* Dagys, *Zugmayerella koessenensis* (Zugmayer), *Sinucosta emmrichi* (Suess), *Oxycolpella oxycolpos* (Emmrich), *Neoretzia superbescens* (Bittner), *Amphiclina intermedia* Bittner, *A. taurica* Moiseev, *Rhaetina taurica* Moiseev, *Triadithyris gregariaformis* (Zugmayer). Besides these, Dagis (1963, 1974) determined *Rhaetina* cf. *R. pyriformis* (Suess), *R. turcica* (Bittner), *Zeilleria bukowski* (Bittner), *Aulacothyropsis almensis* (Moiseev).
Loc. 117/sample 2
A brachiopod assemblage analogous to locality 117/1 has been collected from pink micritic limestone. Only three species – *Amphiclina intermedia* Bittner, *Rhaetina taurica* (Bittner), and *Zeilleria bukowski* (Bittner) – are absent from those listed in Loc. 117/1.

Loc. 117/sample 3
Foraminifers. *Tolypammina irregularis* (Salaj, Borza & Samuel), *T. gregaria* Wendt, *Ammobaculites* sp., *Duotaxis inflatus* (Kristan-Tollmann), *Gaudryina triadica* Kristan-Tollmann, *G. racema* Trifonova, *Planiinvoluta deflexa* Leischner, *Semiinvoluta bicarinata* Blau, *Angulodiscus parallelus* (Kristan-Tollmann), *Arenovidalina chialingchiangensis* Ho, *A. depressa* (Luperto), *Ophthalmidium carinatum* Leischner, *O. fusiformis* (Trifonova), *O.* cf. *O. martanum* Farinacci, *O. tori* Zaninetti & Broennimann, *Sigmoilina schaeferae* Zaninetti, Altiner, Dager & Ducret, *Nodosaria* cf. *N. angulocamerata* Efimova, *N.* cf. *N. elongata* (Salaj, Borza & Samuel), *N.* aff. *N. shablensis* Trifonova, *Lenticulina* sp., *Astacolus* sp., *Turrispirillina* sp.
Brachiopods. *Euxinella anatolica* (Bittner), *Robinsonella mastakanensis* Moiseev, *Laballa slavini* Dagys, *Zugmayerella koessenensis* (Zugmayer), *Sinucosta emmrichi* (Suess), *Oxycolpella oxycolpos* (Emmrich), *Neoretzia superbescens* (Bittner), *Rhaetina pyriformis* (Suess), *R. gregaria* (Suess), *Zeilleria moisseievi* Dagys, *Z. austrica* (Zugmayer).
Ammonoids. *Megaphyllites* sp.
Crinoids and corals are also present.

Loc. 118

This block (4.5 m × 2.0 m) is located 135 m upstream from Loc. 117 on Izvestnyakovy Creek and is composed of light gray micritic limestone. It has yielded the following brachiopods – *Rhaetina taurica* Moiseev, *Neoretzia superbescens* (Bittner), *Zeilleria austrica* (Zugmayer).

Loc. 119

Down the creek from locality 117, four limestone blocks ranging from 1.5-5 m across were found, as well as smaller angular limestone fragments (Fig. 7A).

Loc. 119/sample 1, 929-1

This is the largest block, about 5 m across, and consists of a coarse biocalcarenite grainstone with radiaxal cement and mud late infilling. The skeletal elements are crinoids, brachiopods, echinoids, gastropods, sponges, foraminifers and intraclasts. The environment is of a shallow, high-energy carbonate platform.

Foraminifers. *Tolypammina gregaria* Wendt, *Trochammina almtalensis* Koehn-Zaninetti, *T. jaunensis* Broennimann & Page, *Duotaxis inflatus* (Kristan-Tollmann), *D. metula* Kristan, *Gaudryina triadica* Kristan-Tollmann, *G. triassica* Trifonova, *Palaeolituonella meridionalis* (Luperto), *Textularia* ex gr. *T. exigua* (Schwager), *Endoteba austrotriadica* (Oberhauser), *E. kuepperi* (Oberhauser), *Malayspirina bicamerata* (Salaj), *M. wirtzi* (Koehn-Zaninetti), "*Calcitornella*" *gebzeensis* Dager, *Planiinvoluta carinata* Leischner, *Coronipora etrusca* (Pirini), *Semiinvoluta bicarinata* Blau, *S. clari* Kristan, *S. violae* Blau, *Lamelliconus turris* (Frentzen), *L. multispirus* (Oberhauser), *Trochonella granosa* (Frentzen), *Arenovidalina chialingchiangensis* Ho, *Ophthal-midium exiguum* Koehn-Zaninetti, *O. fusiformis* (Trifonova), *O. leischneri* (Kristan-Tollmann), *O. lucidum* (Trifonova), *O. triadicum* (Kristan), *Sigmoilina bystrickyi* Salaj, Borza & Samuel, *S. plectospira* (Oravecz-Scheffer), *Galeanella panticae* Zaninetti & Broennimann, *Miliolipora cuvillieri* Broennimann & Zaninetti, *Ophtalmipora*? sp., *Nodosaria* sp. 1, *Septalingulina* cf. *S. tetrasepta* He & Notling, *Austrocolomia* ex gr. *A. canaliculata* (Kristan-Tollmann), *Lenticulina rectangula* Kristan-Tollmann, *Astacolus* sp., *Duostomina* sp.

Brachiopods. *Oxycolpella oxycolpos* (Emmrich), *Rhaetina pyriformis* (Suess).

Loc. 119/sample 2, 929-2

This sample is a fine-grained, mud supported biocalcilutite with crinoids, foraminifers, thin-shelled ostracods and bryozoan fragments. The numerous cavities with light mud infilling are typical of a mudmound on a shallow slope.

Foraminifers. *Gaudryina triassica* Trifonova, *Coronipora etrusca* (Pirini), *Semiinvoluta bicarinata* Blau, *Angulodiscus* ex gr. *A. expansus* (Kristan-Tollmann), *Paraophthalmidium* sp., *Ophthalmidium fusiformis* (Trifonova), *O.* cf. *O. martanum* Farinacci, *O.* sp. 1, *Quinqueloculina*? *nucleiformis* Kristan-Tollmann, *Sigmoilina bystrickyi* Salaj, Borza & Samuel, *S. plectospira* (Oravecz-Scheffer), *S. schaeferae* Zaninetti, Altiner, Dager & Ducret, *Nodosaria* cf. *N. elongata* (Salaj, Borza & Samuel), *N. nitida elongata* Franke, "*Frondicularia woodwardi*" Howchin, *Austrocolomia canaliculata* (Kristan-Tollmann), *A. marschalli* Oberhauser, *Lenticulina* sp.

Brachiopods. *Euxinella anatolica* (Bittner), *Septaliphoria fissicostata* (Suess), *Crurirhynchia kiparisovae* Dagys, *Laballa suessi* (Winkler), *Oxycolpella oxycolpos* (Emmrich), *O. robinsoni* Dagys, *Amphiclina taurica* Moiseev, *Triadithyris gregariaformis* (Zugmayer).

Loc. 119/sample 3

This block consists of graded, resedimented pinkish fine wackestone – coarse skeletal packstone with echinoids, crinoids, brachiopods and foraminifers. This is a considered to be a distal slope deposit.

Foraminifers. *Tolypammina gregaria* Wendt, *Coronipora etrusca* (Pirini), *Semiinvoluta bicarinata* Blau, *Lamelliconus turris* (Frentzen), *Ophthalmidium leischneri* (Kristan-Tollmann), *O. lucidum* (Trifonova), *Sigmoilina bystrickyi* Salaj, Borza & Samuel, *S. schaeferae* Zaninetti, Altiner, Dager & Ducret, *Miliolipora cuvillieri* Broennimann & Zaninetti, *Nodosaria* sp. 1, *Rectoglandulina*? sp., *Lenticulina* sp., *Duostomina* sp., *Turrispirillina*? *licia licia* Blau.

Loc. 121a

Numerous exotic blocks of gray limestone occur

near Drovyanka Village. The species *Monotis caucasica* (Wittenburg) and *M. haueri* Kittl were found (determination of A. Moiseev and I. Polubotko).

Loc. 132
A brachiopod assemblage of Shvanov Ravine contains *Costirhynchia mentzeli* (Buch), *Hirsutella hirsuta* (Alberti), *Mentzelia* sp., *Koeveskallina koeveskalliensis* (Boeckh), *Punctospirella* cf. *P. fragilis* (Schlotheim), *Costispiriferina* cf. *C. manca* (Bittner), *Angustothyris angustaeformis* (Boeckh). This assemblage is of Anisian age. However, we cannot confirm that this assemblage is coming from an exotic block, and not from the matrix.

SIMFEROPOL AREA
Loc. 130
The second important location of Triassic exotic blocks is in the Salgir River Basin in the Simferopol area (Fig. 4A). Some blocks, separated from each other, were observed near Petropavlovka Village (Loc. 130) in the sandstone and conglomerate of the Eskiorda Series.
The block of Loc. 130 is a crinoid and algal lime-packstone yielding abundant brachiopods, single ammonoids, bivalves, and gastropods. The brachiopod assemblage contains – *Euxinella anatolica* (Bittner), *Laballa seessi* (Winkler), *L. slavini* Dagys, *Sinucosta emmrichi* (Suess), *Zugmayerella koessensis* (Zugmayer), *Oxycolpella oxycolpos* (Emmrich), *Amphiclina taurica* Moiseev, *Rhaetina taurica* Moiseev, *Lobothyris* sp., *Zeilleria bukowski* (Bittner), *Aulacothyropsis elmensis* (Moiseev). This data is compiled from earlier workers (Moiseev 1932; Dagis 1963, 1974; Shalimov & Slavin 1973).
The following ammonoids occur with these brachiopods: *Paracladiscites diuturnum* Mojsisovich, *Arcestes* ex gr. *A. intuslabiatus* Mojsisovich, and *Platites* sp. Shevyrev (1990) correlated to the upper Rhaetian or the *Choristoceras marshi* zone of the standard scale.

ANALYSIS OF FAUNAL ASSEMBLAGES
Ammonoids
Ammonoids are rare in the pink limestone outcropping on the upper part of Izvestnyakovy Creek (Loc. 117/3). Only one shell, *Megaphyllites* sp., was preserved well enough to be determined by us. Representatives of this genus are recorded from the upper part of the Lower Triassic into the Upper Triassic. Within the Alpine Region, they are known only from the upper Anisian to Rhaetian.

Foraminifers
Pronina & Vuks (1996) gave the first detailed information about Triassic foraminifers of the Crimea. All of the foraminifers that were studied occur in exotic blocks (Locs 116, 117, 119; Figs 4B, 7). The assemblages are of similar generic and specific composition, which allows them to be considered the same age. They are characterized by the presence of miliolids and involutinids, the most significance foraminifers for dating Lower Mesozoic deposits.
In this assemblage, the following species are known in Norian-Rhaetian deposits: *Semiinvoluta clari* Kristan, *Angulodiscus parallelus* (Kristan-Tollmann), *A.* ex gr. *A. expansus* (Kristan-Tollmann), *Sigmoilina bystrickyi* Salaj, Borza & Samuel, *S. schaeferae* Zaninetti, Altiner, Dager & Ducret, *Galeanella panticae* Zaninetti & Broennimann, *Miliolipora cuvillieri* Broennimann & Zaninetti. In addition, species are present that occur in deposits not older than the Rhaetian, and sometimes even in younger deposits; *Semiinvoluta bicarinata* Blau, *Trochonella granosa* Frentzen, *Ophthalmidium leischneri* (Kristan-Tollmann), *Septalingulina tetrasepta* He & Norling, and *Turrispirillina*? *licia licia* Blau.
Considered together, the foraminiferal assemblages of the Crimea are similar: to the late Norian (Sevatian)-Rhaetian of the Khodz Group of the Northwest Caucasus (Efimova 1975; Anonymous 1991); to the late Norian (Lacian-Sevatian) *Miliolipora cuvillieri* standard zone of the Carpathian-Balkan and Hellenic Realm (Salaj *et al.* 1983, 1988); to the upper Norian Kocagedik unit of Turkey (Altiner & Zaninetti 1981); and to the Norian-Rhaetian Asinepe Limestone of Seram, Indonesia (Al-Shaibani *et al.* 1983).
Accordingly, we conclude that the age of the foraminiferal assemblages of the Crimea can be either late Norian or Rhaetian. Most likely, the

age is Rhaetian, because species are in the associations whose distribution is limited to the Rhaetian. However one Rhaetian index species, *Triasina hantkeni* Majzon, was not found in the Crimea blocks.

Brachiopods

Moiseev (1926, 1932) studied the first Triassic brachiopods from exotic blocks of the Crimea. Later, the numerous brachiopods collected by Moiseev, Shalimov, and Slavin were determined and partly described by Dagis (1963, 1974). The brachiopod assemblages were considered to be the of mixed Norian-Rhaetian age.

Dagis identified the Middle Triassic brachiopod assemblage in Shvanov Ravine in the Bodrak River Basin (Loc. 132). It contains *Costirhynchia mentzeli* (Buch), *Hirsutella hirsuta* (Alberti), *Mentzelia* sp., *Koeveskallina koeveskalliensis* (Boeckh), *Punctospirella* cf. *P. fragilis* (Schlotheim), *Costispiriferina* cf. *C. manca* (Bittner), and *Angustothyris angustaeformis* (Boeckh). These brachiopods are of Anisian age (Dagis & Shvanov 1965). However, we cannot confirm that this assemblage is characteristic of the exotic blocks, and not of the matrix.

New investigation of the brachiopod assemblages from the numerous limestone blocks and pebbles of the Crimea confirms the specific composition, and more precisely, defines their stage and zonal position. Analysis of all Triassic brachiopod associations from investigated exotic blocks shows that there is only one distinctive brachiopod assemblage of Rhaetian age. It occurs in the large (Loc. 117) and smaller (Locs 116, 118, 119) limestone blocks and pebbles exposed in the Alma River Basin, and in the valley of Izvestnyakovy Creek (Fig. 4B, 7). The same brachiopod assemblage has been found in the Salgir River Basin near Petropavlovka Village (Loc. 130).

Rhaetian species from different regions of the West Tethys dominate this assemblage. They are – *Robinsonella mastakanensis* Moiseev, *Septaliphoria fissicostata* (Suess), *Laballa suessi* (Winkler), *Zugmayerella koessenensis* (Zugmayer), *Sinucosta emmrichi* (Suess), *Oxycolpella oxycolpos* (Emmrich), *Neoretzia superbescens* (Bittner), *Rhaetina gregaria* (Suess), *R. pyriformis* (Suess), *Triadithyris gregariaformis* (Zugmayer), *Zeilleria austrica* (Zugmayer), and *Z. bukowski* (Bittner).

The Crimea brachiopod assemblage is most similar to the Rhaetian brachiopods from the Koessen beds of Alps (Dagis 1974). The following species are common – *Septaliphoria fissicostata* (Suess), *Laballa suessi* (Winkler), *Zugmayerella koessenensis* (Zugmayer), *Sinucosta emmrichi* (Suess), *Oxycolpella oxycolpos* (Emmrich), *Rhaetina gregaria* (Suess), and *Triadithyris gregariaformis* (Zugmayer). The Crimea brachiopod assemblage is also similar to Rhaetian brachiopods of Drnava Slovenia. The common forms are *Septaliforia fissicostata* (Suess), *Laballa suessi* (Winkler), *Zugmayerella koessenensis* (Zugmayer), *Sinucosta emmrichi* (Suess), *Neoretzia superbescens* (Bittner), *Rhaetina pyriformis* (Suess), *Triadithyris gregariaformis* (Zugmayer), and *Zeilleria austrica* (Zugmayer) (Dagis 1974). Likewise, the assemblage is comparable to *Majkopella manzavinii* beds of Turkey. The common forms are *Euxinella anatalica* (Bittner), *Laballa suessi* (Winkler), *Sinucosta emmrichi* (Suess), *Rhaetina turcica* (Bittner), *Zeilleria austrica* (Zugmayer), and *Z. bukowski* (Bittner) (Bittner 1892). Finally, they are similar to the brachiopods collected from exotic blocks of Balkanian. The common forms are *Zugmayerella koessenensis* (Zugmayer), *Sinucosta emmrichi* (Suess), *Oxycolpella oxycolpos* (Emmrich), *Amphiclina intermedia* Bittner, *Rhaetina gregaria* (Suess), and *R. turcica* (Bittner) (Dagis 1963).

The red limestone of the upper part of the Khodz Group of the Northwest Caucasus, that lies above beds with *Monotis caucasica*, is the same age as the Crimea exotic blocks. They both contain species in common – *Euxinella anatolica* (Bittner), *Crurirhynchia kiparisovae* Dagys, *Zugmayerella koessenensis* (Zugmayer), *Sinucosta emmrichi* (Suess), *Oxycolpella oxycolpos* (Emmrich), *Neoretzia superbescens* (Bittner), *Amphiclina intermedia* Bittner, *A. taurica* Moiseev, *Rhaetina turcica* (Bittner), *R. pyriformis* (Suess), *Zeilleria bukowski* (Bittner), and *Z. moissejevi* Dagys.

All the above-mentioned brachiopod assemblages, considered earlier as Norian-Rhaetian, are actually the youngest Rhaetian associations. We

agree with Shevryev (1990, 1995) that they can be attributed to the *Vandaites sturzenbaumi* zone. Co-occurrence of these brachiopod assemblages and such ammonoid species as *Paracladiscites diuturnus* Mojsisovich, *Arcestes* ex gr. *A. intuslabiatus* Mojsisovich, and *Platites* sp., that were established as beds with *Platites-Rhacophyllites* near Petropavlovka Village (Shevyrev 1995), allow us to specify the stage and zonal position of this association. An analogous, but more diverse, ammonoid association occurs together with Rhaetian brachiopods in other regions of the Tethys, including the Northwest Caucasus in the upper part of the Khodz Group. It is represented by the presence of *Paracladiscites diuturnus* Mojsisovich, *Megaphyllites insectus* (Mojsisovich), *Stenarcestes leiostracus* Mojsisovich, *Arcestes* ex gr. *A. intuslabiatus* Mojsisovich, *Rhacophyllites debilis* (Hauer), *Platites polydactilus* (Mojsisovich) (Shevyrev 1995). Everywhere in the West Tethys, Rhaetian brachiopod assemblages usually occur in pink or red limestone.

The Norian-Rhaetian, but not Rhaetian age, of the above-mentioned mixed brachiopod association has been determined by the presence in these beds of Norian ammonoids. However, Shevyrev (1990) believes that the appearance and great development of heteromorph ceratites is an important event in the Late Triassic ammonoid succession. It allows one to consider the Rhaetian as important in the development of Triassic ammonoids. Nevertheless, we are following Dagis (Dagis & Dagis 1990) in drawing the Rhaetian lower boundary at the base of the *Cachloceras suessi* zone.

Summary of the Triassic

1. Triassic exotic blocks contain rich assemblages of foraminifers, brachiopods, rarer ammonoids, bivalves, and sphictozoans. Reworked forms are practically absent.

2. The taxonomic composition of the brachiopods and ammonoids shows the greatest similarity to Rhaetian assemblages of the West Tethys, the Northwest Caucasus, the Alps, the Carpathians, and Turkey. The foraminifers are most similar to those in the Northwest Caucasus, the Carpathian-Balkan and Hellenic Realm, Turkey, and Indonesia.

3. Some limestone blocks (Loc. 121a) containing abundant *Monotis* belong to the *Sagenites quinquepunctatus* zone of the Sevatian (Dagis & Dagis 1990), or to the upper part of the Norian.

4. The analysis of faunal elements from Triassic exotic blocks (Locs 116-119, 130) allows us to consider that they are of Rhaetian age and according to Dagis & Dagis (1990) belong to the *Vandaites sturzenbaumi* zone.

5. The Anisian fauna from the Bodrak River Basin probably does not come from an exotic block.

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Upper Permian and Triassic of the Precaspian Depression: stratigraphy and palaeogeography

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ABSTRACT
The stratigraphic serie of the Precaspian Depression during the Upper Permian and the Triassic is analysed. Data from seismic sections and from numerous boreholes are used. The lithological composition and the palaeontological content are cleared for all the time interval. Three palaeogeographical maps are drawing for the Kazanian, the Lower Triassic and the Middle Triassic. The evolution of palaeoenvironments is restored in relation to the tectonic events and the fluctuations of the Boreal Sea and the Palaeo-Tethys Ocean.

KEY WORDS
Precaspian Depression,
Upper Permian,
Triassic,
stratigraphy,
palaeogeography.

RÉSUMÉ
Le Permian supérieur et le Trias de la Dépression Précaspienne : stratigraphie et paléogéographie.
La série stratigraphique de la Dépression Précaspienne est analysée pour le Permien supérieur et le Trias. Les données de profils sismiques et de nombreux forages sont utilisées. La composition lithologique et le contenu paléontologique sont précisés pour l'intervalle de temps considéré. Trois cartes paléogéographiques sont établies pour le Kazanien, le Trias inférieur et le Trias moyen. L'évolution des paléoenvironnements est établie en relation avec les événements tectoniques et les fluctuations de la mer Boréale et de l'océan Paléo-Téthysien.

MOTS CLÉS
Dépression Précaspienne,
Permien supérieur,
Trias,
stratigraphie,
paléogéographie.

INTRODUCTION

The Upper Permian and the Triassic of the Precaspian Depression and adjacent areas are represented by marine and continental deposits. The complex original relationships between these deposits have been modified by the salt tectonogenesis. The salt domes are widely distributed (Fig. 1) and the upper part is often eroded. The most complete sections are in the depressions between the domes. We present here new data which complete the previous work (Kukhtinov 1976, 1984) on stratigraphy and depositional conditions.

STRATIGRAPHY (Table 1)

The Upper Permian (P_2)

The Upper Permian deposits are irregularly studied. They were drilled during the oil and gas prospecting, mainly on the borders of the Depression (Figs 2-5). In the central part of the basin, in the Aralsor 1 borehole (locality 2 on Figs 6, 7), the Upper Permian succession is recognized between 6806 and 5492 m. The base of the Upper Permian is not reached. The most complete sequence is located on the eastern border of the Depression where all substages are characterised by their palaeontological content (example Lugov borehole, No. 45 on Figs 6, 7).

The Ufimian (P_2u)

In the eastern part of the Depression, two terrigenous units were recognised (Fig. 6). The lower one (P_2u_1) is grey (200-300 m) and has not clear boundary with the underlying Kungurian. It is composed of fine-grained sandstones, claystones and aleurolites – aleurolites is more or less equivalent to siltstone in Russian literature. The upper unit (P_2u_2) is red (200-300 m) and is mainly represented by sandstones. In both units, anhydrites and salt lenses are sometimes interlayered and typical ostracods of the *Darwinula angusta* zone from the Russian platform Ufimian (see for example Molotovskaya 1997) are recovered (*Darwinula lubimovae* Kashevarova, *D. angusta* Mandelstam, *D. lanzetiformis* Kashevarova, *D. fainae* Belousova, *D. burajevoensis* Palant, *D.* cf. *trita* Palant, *D.* cf. *pyriformis* Kashevarova). The bivalve *Palaeomutela* cf. *stegocephalum* Nechaev, as well as miospores and conchostraceans, permit the correlations with the synchronous deposits of Aktjubian Pre-Uralian zone.

In the central part of the Depression, the red argilites and sandstones with inclusions of anhydrite drilled in the Aralsor well (6630-6806 m) are related to the Ufimian (Fig. 6). The thickest Ufimian deposits (more than 581 m) were drilled in Linjovka 8 well (locality 43 on Fig. 7) on the northern edge. They are composed of grey and red terrigenous, carbonated and sulfate-halogenous rocks with non marine ostracods (*Darwinula abunda* Mandelstam, *D. acervalis* Mandelstam, *D.* aff. *parphenovae* Belousova, *D. subaclinis* Zhernakova), bivalves (*Palaeomutela* ex gr. *ovataeformis* Gussev, *P.* cf. *pseudoumbonata* Gussev, *Anthraconaia rhomboides* Netschajev), conchostraceans, fishes and charophytes.

In northern and western edges of the Depression, the Ufimian is defined between the Kungurian anhydrites and the Kazanian clays and carbonates; 30 to 70 m of red and grey sulphate-terrigenous, halogenic and rarely carbonates rocks are recognised. In the south-western part, the Ufimian terrigenous deposits (63 to 1242 m) are distinguished by spores and pollens. The spore and pollen spectra shows predominance of *striatiti* (up to 52%) and Vittatina (27 to 37%). These deposits are included in the Volozhkovskaya suite (without subdivision) from Ufimian-Kazanian (Pronicheva & Savinova 1982).

The Kazanian Stage (P_2kz)

It is represented by two substages (lower and upper) in most of the Precaspian Depression and its northern and western adjacent areas.

Lower Kazanian substage (P_2kz_1). The Kalinovskaya suite is composed of clays, dolomites, limestones, rarely sandstones with marine macro- and microfauna: brachiopods [*Cancrinella cancrini* Verneuil, *Beecheria netschaevi* Grigorieva, *Cleiothyridina reussiana* (Keiserling), *C. pectinifera* (Sowerby)], bivalves *Pseudomonotis*

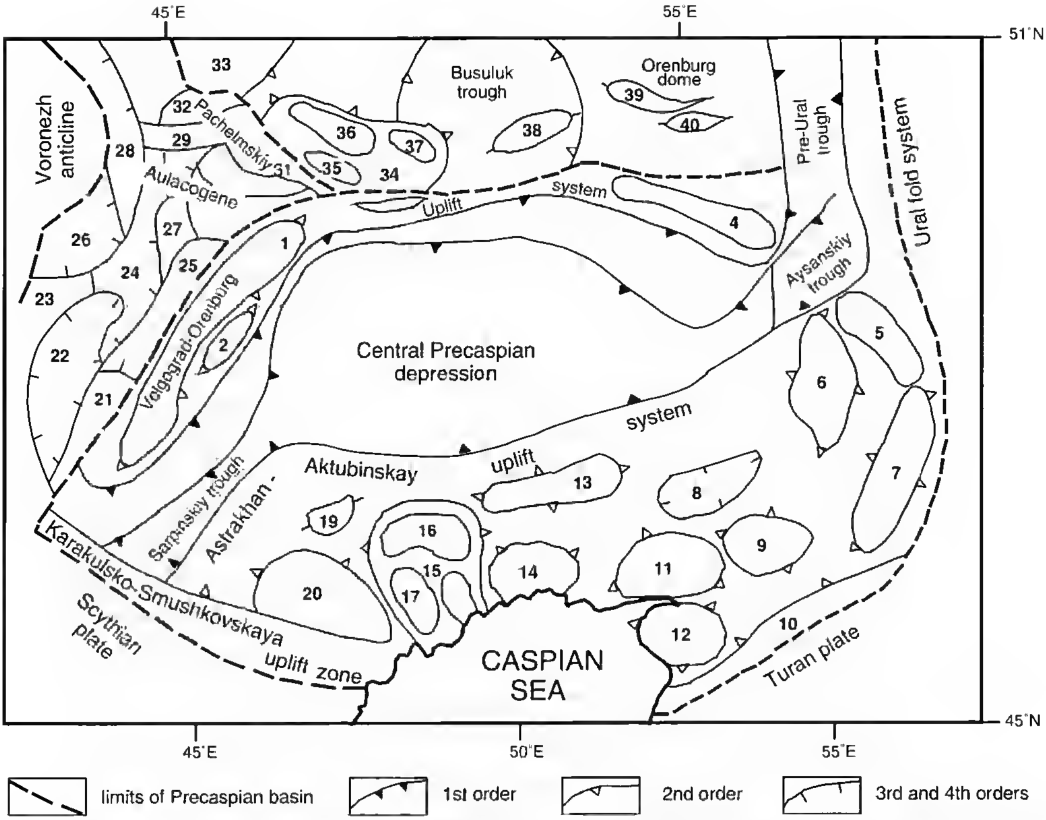

FIG. 1. — Tectonic chart of the Precaspian Depression. Tectonic features 1, Akhtubinsk-Palassowski megamound; **2**, Dzhanybeckoe rise; **3**, Altatinsk-Nikolskiy mound; **4**, Karachaganak-Koblandinskay uplift; **5**, Temirskiy dome, **6**, Kzyldsharskiy dome; **7**, Zharkamyssiy dome; **8**, Dossorskiy trough; **9**, Biikzhalskiy dome; **10**, South Emba uplift; **11**, Guriev dome; **12**, Karaton-Tengiz uplift; **13**, Zhaykskiy dome; **14**, North-Caspian dome; **15**, Akkolskiy dome; **16**, Myntobinskay uplift; **17**, Kobyakovskoe uplift; **18**, Octyabrskoe uplift; **19**, Azgirskoe uplift; **20**, Astrakan dome; **21**, Suvodskaya uplift; **22**, Olkhovskay depression; **23**, Archedino-Don mound; **24**, Zhirnovsko-Umetovskiy mound, **25**, Antipovsko-Sherbakovskiy mound; **26**, Tersinskaya depression; **27**, Zolotovsko-Kamenskaya uplift; 28, Karamyshskaya uplift, **29**, Elshano-Sergievskiy mound; **30**, Stephovskiy mound; **31**, Voskeresenskaya depression; **32**, Saratov displacements; **33**, Kazanlinskiy monud; **34**, Pugachevskiy dome; **35**, Marievskaya uplift; **36**, Balakovskaya uplift; **37**, Klintsovskay uplift; **38**, Kamelik-Chaganskiy mound; **39**, Zemlyanskiy mound; **40**, Syrtovskiy mound.

elengatula Netschajev, *Parallelodon kingi* Verneuil, *P.* cf. *striatus* (Schlotheim), *Edmondia elongata* House, *Bakevellia (Bakevellia) ceratophaga* (Schlotheim)], bryozoa [*Dyscritella incrustata* Morozova], foraminiferas [*Palaeonubecularia uniserialis* Reitlinger, *P. fluxa* Reitlinger, *Geinitzina pusilla* Grozdilova, *G. spandeli* Tscherdynzev, *G.* cf. *postcarbonica* Spandel, *Nodosarina elabugae* Tscherdynzev, *N. netschevi* Tscherdynzev, *Spandellina* ex gr. *cordiformis* Gerce], ostracods [*Healdia subtriangula* Kotschetkova, *H. simplex* Roundy, *Healdianella vulgata* Kotschetkova, *H. parallela* Knight, *H.* ex gr. *osagensis* Kellett, *H.* ex gr. *panda* Kotschetkova, *Cavellina*? cf. *unica* Kotschetkova, *C.* ex gr. *edmistonae* (Harris & Lalicker)]. The thickness varies from 0 to 168 m.

In the south-western part of the Depression, the upper Volozhkovskaya suite is composed of red and grey terrigenous rocks. In the south, the Zhambay 22 well (noted 3 on Fig. 7) shows under the Triassic, terrigenous rocks with brachiopods, pelecypods, ostracods (*Darwinula* sp., *Moorea* cf. *facilis* Schneider) of lower Kazanian substage. In the east of the Precaspian Depression, the series (700 m), composed of regularly interlaid sandstones, aleurolites, argilites and limestones with locally salt lenses, is synchronous

<table>
<tr><th rowspan="2"></th><th rowspan="2">STAGE</th><th rowspan="2" colspan="2">HORIZON</th><th rowspan="2">SERIE</th><th colspan="3">SUITE</th></tr>
<tr><th>West</th><th>Centre and North-West</th><th>East</th></tr>
<tr><td rowspan="3">T3</td><td>Rhaetian</td><td>Kusankudukian</td><td>T_{3ks}</td><td rowspan="6">Aralsorskaya</td><td rowspan="3"></td><td rowspan="2"></td><td>Kusankuduskaya</td></tr>
<tr><td>Norian</td><td rowspan="2"></td><td rowspan="2"></td><td>Shalkarskaya-T_{3sk}</td></tr>
<tr><td>Carnian</td><td>Koktinskaya</td><td>Koktinskaya-T_{3kk}</td></tr>
<tr><td rowspan="5">T2</td><td rowspan="3">Ladinian</td><td>Chobdian</td><td>T_{2ch}</td><td>Barmantsakskaya</td><td></td><td>Chobdinskaya-T_{2ch}</td></tr>
<tr><td>Akmamykian</td><td>T_{2ak}</td><td rowspan="2">Sarpinskaya</td><td>Akmamykskaya</td><td>Akmamykskaya-T_{2ak}</td></tr>
<tr><td>Masteksajskian</td><td>T_{2ms}</td><td>Masteksajskaya</td><td>Masteksajskaya-T_{2ms}</td></tr>
<tr><td rowspan="2">Anisian</td><td>Inderian</td><td>T_{2in}</td><td rowspan="2">Akmajskaya T_{2ak}</td><td>Inderiskaya</td><td>Inderskaya</td><td rowspan="2">Kiiskaya / Tasshijskaya T_{2ts}</td></tr>
<tr><td>Eltonian</td><td>T_{2el}</td><td>Eltonskaya</td><td>Eltonskaya</td></tr>
<tr><td rowspan="7">T1</td><td rowspan="4">Olenekian</td><td rowspan="4">Baskuntchakian</td><td rowspan="4">T_{1bs}</td><td rowspan="4">Baskuntchakskaya</td><td>Enotaevskaya</td><td rowspan="4">Zhulidovskaya</td><td rowspan="4">Akzharsajskaya T_{1kz}</td></tr>
<tr><td>Bogdinskaya</td></tr>
<tr><td>Aktubinskaya</td></tr>
<tr><td>Buzulukskaya</td></tr>
<tr><td rowspan="3">Induan</td><td rowspan="3">Ershovian</td><td rowspan="3">T_{1er}</td><td rowspan="3">Prikaspinjskaya</td><td rowspan="3">Bugrinskaya</td><td rowspan="3">Ershovskaya</td><td>Kokzhidinskaya-T_{1kz}</td></tr>
<tr><td>Sorkolskaya-T_{1sk}</td></tr>
<tr><td>Blaktykolskaya-T_{1bl}</td></tr>
<tr><td rowspan="7">P2</td><td rowspan="3">Tatarian P_{2t}</td><td>Viatkian</td><td>P_{2vt}</td><td rowspan="7"></td><td rowspan="3">Batyrmolinskaya</td><td>Viatkian</td><td></td></tr>
<tr><td>Severodvinian</td><td>P_{2sd}</td><td>Sererodvinian</td><td>Sererodvinian</td></tr>
<tr><td>Urzhmian</td><td>P_{2ur}</td><td>Urzhumian</td><td>Urzhumian</td></tr>
<tr><td rowspan="2">Kazanian P_{2kz}</td><td>upper Kazanian</td><td>P_{2kz2}</td><td rowspan="4">Volozhkovskaya</td><td>upper Kazanian</td><td>upper Kazanian</td></tr>
<tr><td>lower Kazanian</td><td>P_{2kz1}</td><td>Kalinovskaya</td><td>Kalinovskaya</td></tr>
<tr><td rowspan="2">Ufimian P_{2u}</td><td>upper Ufimian</td><td>P_{2u2}</td><td>Sheshmian</td><td>Sheshmian-P_{2sh}</td></tr>
<tr><td>lower Ufimian</td><td>P_{2u1}</td><td>Solikamian</td><td>Solikamian-P_{2sl}</td></tr>
</table>

TABLE 1. — Upper Permian and Triassic stratigraphic subdivisions of the Precaspian Depression.

with the Kalinovskaya suite. The organic remains are crinoids, ostracods (*Sinusuella* cf. *ignota* Spizharskyi, *Darwinula varsanofievae* Belousova, *D. irinae* Belousova, *D. isetica* Starojilova, *D. accomodata* Starojilova, *D.* ex gr. *tichwinskaje* Belousova, *Suchonella onega* Belousova, *S. belebeica* Belousova, *S. sacmarensis* Starojilova, *Darwinuloides edmistonae* Belousova, *D. sentjakensis* Sharapova, *D. triangula* Belousova), non marine pelecypods, miospores. They allow the comparison with the Akjubian (lower Kazanian or Kazanian) of Pre-Ural and Russian platform.

Upper Kazanian substage (P_2kz_2). The upper Kazanian substage is everywhere represented by terrigenous rocks. To the east of the Depression, the series is composed of sandstones with conglomerate at the bottom and argilite interbedded (mainly in the upper part). In this series (400-500 m), they are quite often non-marine bivalves [*Palaeomutela* ex gr. *krotovi* Nechaev, *P.* ex gr. *doratioformis* Gussev, *P.* cf. *umbonata* (Fischer), *P.* cf. *vjatkensis* Gussev, *Palaeanodonta rhomboidea* (Nechaev)], ostracods [*Darwinula varsanofievae* Belousova, *D. vinocurovi* Belousova, *D. accomodata* Starojilova, *D. inornatina* Belousova, *D. alexandrinae* Belousova, *Suchonella belebeica* Belousova, *S. onega* Belousova, *S. serpula* Belousova, *Darwinuloides sentjakensis* Sharapova, *D. edmistonae* Belousova, *D. triangula* Belousova, *Sinusuella ignota* Spizharskyi], spores and pollen which are characteristic of the whole Kazanian stage or of its upper substage in the most areas of the Russian platform.

In the central part of the Depression, the upper Kazanian substage is composed of red aleurolites and argilites with marine and non-marine ostracods [*Healdia* sp., *Healdianella vulgata* Kotschetkova, *Healdianella* sp., *Monoceratina* aff. *exilis* (Schneider), *Schneideria* ex gr. *kotschetkovae* Starojilova, *Darwinula* sp., *Suchonella sacmarensis* Starojilova, *S. tichwinskaja* (Belousova), *Placidea* sp., *Tomiella* sp.]. The thickness reaches 345 m.

On the northern Depression border, on the Kalinovskaya suite, the red argilites with anhydrite and salt inclusions, could be palaeontologically correlated with the upper Kazanian deposits

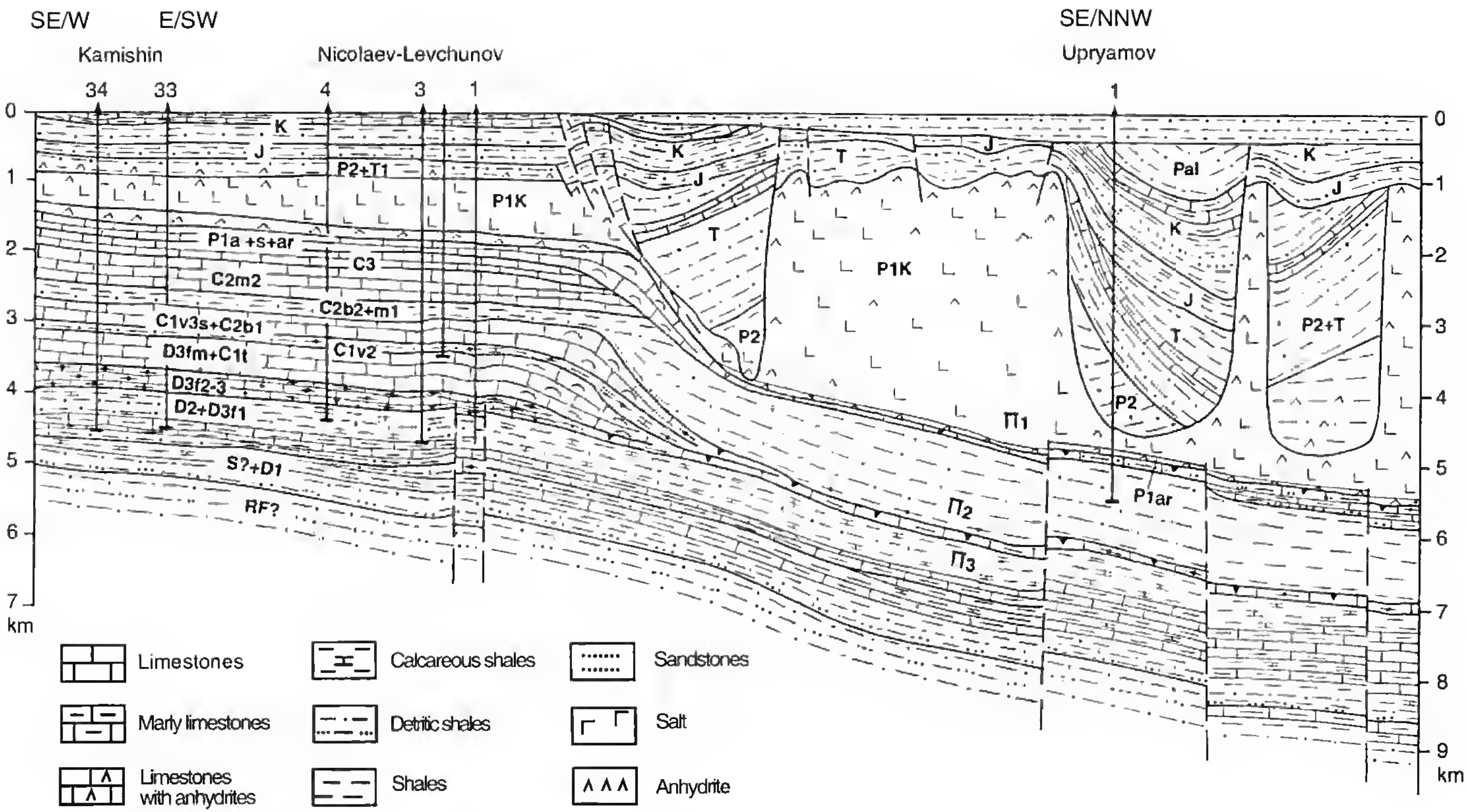

FIG. 2. — Geological-geophysical cross section SP 052 (location on Fig. 7). Western margin-Central part of Precaspian Depression. **PR3/Vd**, Upper Precambrian-Vendian; **FR**, Riphean; **S**, Silurian; **D**, Devonian; **D1**, Early Devonian; **D2**, Middle Devonian; **D3**, Late Devonian; **D3fr**, Frasnian; **D3f1**, early Frasnian; **D3f2**, middle Frasnian; **D3f3**, late Frasnian; **D3fm**, Famennian; **C1**, Early Carboniferous; **C2**, Middle Carboniferous; **C3**, Late Carboniferous; **C1t**, Tournaisian; **C1v**, Visean; **C1v2**, late Visean; **C1v3**, late Visean; **C2b1**, early Bashkirian; **C2b2**, late Bashkirian; **C2m1**, early Moscovian; **C2m2**, late Moscovian; **P1**, Early Permian; **P2**, Late Permian; **P1a**, Asselian; **P1s**, Sakmarian; **P1ar**, Artinskian; **P1k**, Kungurian; **P2kz**, Kazanian; **T**, Triassic; **T1**, Early Triassic; **J**, Jurassic; **K**, Cretaceous; **K1**, Early Cretaceous; **K2**, Late Cretaceous; **Pal**, Palaeogene; **N2**, late Neogene; **Π1**, **Π2**, **Π3**, the three main discontinuities; **F**, major fault.

of the Orenburg Pre-Ural adjacent area.
In other areas, there are no data reliable to the upper Kazanian substage.

The Tatarian Stage (P_2t)

Lower Tatarian substage (P_2t_1). In the eastern part of the Depression, the lower Tatarian is represented by red clays (600-800 m). The ostracods are non-marine (*Darwinula elongata* Lunjak, *D. teodorovichi* Belousova, *D. tichonovichi* Belousova, *D. fragiliformis* Kashevarova, *D. elegantella* Belousova, *D. perlonga* Sharapova, *D. torensis* Kotschetkova, *Suchonella nasalis* Sharapova, *Darwinuloides dobrinkaensis* Kashevarova). Some non marine pelecypods were found (*Palaeanodonta navalis* Nechaev, *P. verneuili* (Amaltisky), *P.* cf. *longissima* Nechaev, *P. fischeri* Amaltisky, *Palaeomutela vjatkensis* Gussev, *P. plana* Amaltisky, *Anthraemaia* sp., *Microdontella* sp.). Spores and pollens confirm the stratigraphic attribution.
In the central part, the Arasol well (locality 2, Figs 6, 7) presents, in the interval 6045-5875 m, red-brown aleurolites and argilites with the non-marine ostracods (*Darwinuloides djurtjulensis* Palant, *Volganella* sp.) attributed to the lower Tatarian.
In the north-western part of the Depression, the series is formed of red clays, aleurolites, sandstones with anhydrite inclusions. It contains charophytes from the Tatarian and ostracods from the lower Tatarian (*Darwinula fragiliformis* Kashevarova, *D. elongata* Lunjak, *Suchonella nasalis* Sharapova) and from the upper Tatarian (*Suchonellina inornata* Spizharskyi, *S. parallela* Spizharskyi, *Suchonella stelmachovi* Spizharskyi). The thickness varies from 0 to 2030 m. Outside of the Depression, similar deposits were observed, with both substage ostracod assemblages, and have a thickness of 0 to 300 m.
In the south-western part, the red terrigenous deposits (about 1200 m) are related to the Tatarian Batyrmolinskaya suite by the presence of spores and pollens (complex j) as well as the ostracod *Suchonellina*.

Upper Tatarian substage (P_2t_2). It is clearly defined on the inner border of the eastern part of the Depression, where it is represented by sandstones and clays (up to 600 m) with ostracods (*Suchonellina inornata* Spizharskyi, *S. parallela* Spizharskyi, *Suchonella stelmachovi* Spizharskyi, *Volganella magna* Spizharskyi) characteristic of the North Dvinian horizon and which allow the correlations with Southern Urals (Molostovskaya 1997).
In the central part, in the Aralsor well (5875-5492 m) (locality 2 on Figs 6, 7), the upper Tatarian presents red and grey sandstones, aleurolites, argillites and clay marls with ostracods of the Viatkian horizon (*Darwinuloides tataricus* Posner, *D. svijazhicus* Sharapova).

As a whole, the Upper Permian has not been studied in full. It is mainly represented by red terrigenous deposits which are traditionally regarded as continental. In general in Russia, the lower Kazanian is marine. On the Depression periphery, there are red interbeds with marine fauna. The maximum thickness of the Upper Permian is located on eastern and southern borders of the Depression.

LOWER TRIASSIC (T_1)

The Lower Triassic deposits of the Precaspian Depression and its adjacent areas overlay with unconformity various Permian levels. In the central part of the Depression, the contact between Permian and Triassic is not known.
The Lower Triassic corresponds here to the international subdivisions (Induan and Olenekian). At the regional scale (Anonymous 1982), it is referred to the Ershovian and Baskunchakian horizons (Table 1).

The Ershovian (T_{1er})

It is accurately defined. It consists of continental red terrigenous deposits (aleurolites, argilites and rare sandstones; Figs 8, 9) with ostracods [*Darwinulla ovalis* Glebovskaya, *D. quadrata* Mischina, *D. dubia* Starojilova, *D. regia* Mischina, *D. gravis* Mischina, *D. pseudoinornata* Belousova, *D. postparallela* Mischina, *Gerdalia wetlugensis* Belousova, *Suchonella posttypica* Starojilova, *S. circula* Starojilova, *S. rykovi* Starojilova (*Darwinula quadrata-D. dubia* zone)], conchostracans [*Vertexia tauriconis* Lutkevich, *Cyclotunguzites gutta* Lutkevich], charophytes [*Vladimiriella globosa* (Saidakovsky), *V. wetlugen-*

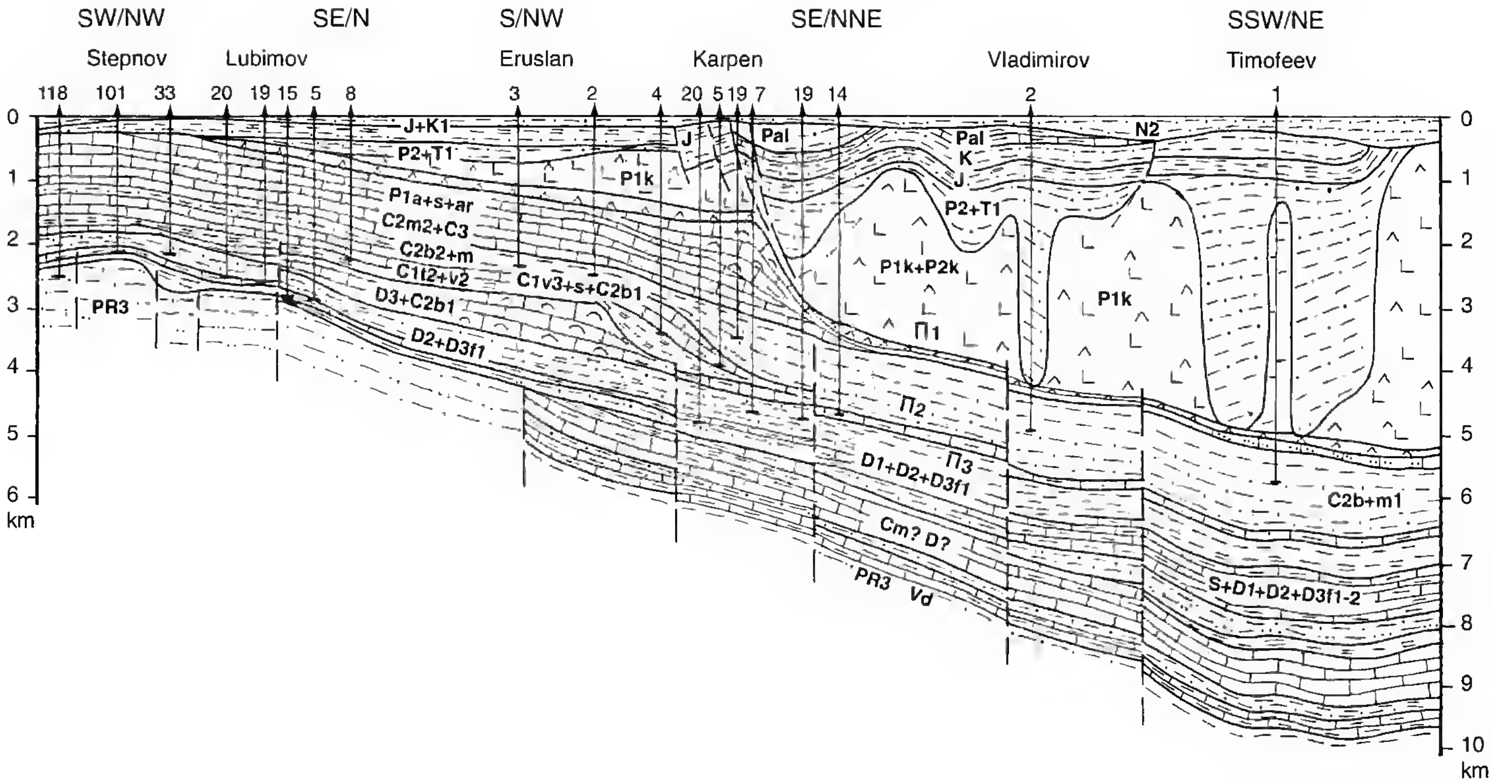

FIG. 3. — Geological-geophysical cross section GG 07 (location on Fig. 7). North-western margin-central part of Precaspian Depression. Legend: see Fig. 2.

sis Saidakovsky], spores and pollen.
Vertexia tauricornis are also known in deposits of middle part of the Vetluzhkaya series of the Moscow syncline, the Kopanskaya suite of the Volgo-Ural anticline, in the middle part of the Korenevskaya suite of the Prypiat trough of the Russian platform and in lower variegated sandstone in Germany (Nordhausen and Bernburg suites).

In the eastern part of the Depression (Blacktykol well; locality 46 on Figs 8, 10), the Blacktykolskaya, Sorkolskaya and Kokzhidinskaya suites are clearly identified. The Blacktykolskaya suite (maximum of thickness 90 m) overlies with unconformity the Permian. It begins by a conglomerate level following by sandstones and clays. To the east, this suite is absent and the Sorkolskaya suite lies on the Permian (Kenkiyak well; locality 44 on Figs 8, 10) with a maximum thickness of 87 m. The Kokzhidinskaya suite (T_{1kz}, Table 1; up to 140 m) is composed of clay sandstones with clay interbeds.
In others areas, the Ershovian horizon is undifferentiated, with red sandy clay deposits. The thickness varies from 0 to 340 m.

The Baskunchakian (T_{1bs})
This horizon combines the marine deposits of the Baskunchakian suite (Table 1) and its continental analogue. In Bolshoi Bogdo Mountain (the only outcrop in the area) four suites (West in Table 1) are distinguished.
The Busulukskaya suite. 96 m of red and grey sandstones without organic remains.
The Akhtubinskaya suite. 64 m of red aleurolite clays with numerous fossils.
Charophytes: *Porochara triassica* (Saidakovsky).
Ostracods: *Clinocypris triassica* (Schneider), *C. elongata* (Schneider), *Darwinula oblonga* Schneider, *Gerdalia longa* Belousova.
Conchostraceans: *Cyclotunguzites gutta* (Lutkevich), *Lioestheria blomi* Novojilov.
Ichtyofauna: *Gnathorhiza triassica baskuntschakensis* Minich, *G. bogdoensis* Minich, *G. otschevi* Minich, *Ceratodus multicristatus feodorensis* Minich (see also Minikh & Minikh 1997).
Bivalves: *Bakewellia lipatovae* Kiparisova.

The Bogdoninskaya suite. 24 to 100 m of variegated clays following by grey clays with limestones interbedded.
Cephalopods: *Tirolites cassianus* (Quenstedt), *Dorikranites bogdoanus* (Buch.), *D. acutus* (Mojsisovich).
Pelecypods: *Mytilus tuarkyrensis* Kiparisova, *Myalina dalailamae* (Verneuil), *Unionites fassaensis* (Wissmann), *U. canalensis* (Catullo).
Brachiopods: *Lingula*.
Tetrapods: *Parotosuchus bogdoanus* S. Woodward.
Fishes: *Ceratodus multicristatus multicristatus* Minich, *Gnathoriza triassica baskuntchakensis* Minich, *G. bogdensis* Minich.
Ostracods: *Triassinella chramovi* Schneider, *Clinocypris cognata* Starojilova, *C. conferta* Starojilova, *C. oleneca* Kukhtinov, *Darwinula rotundata* Luber, *D. parva* Schneider, *D. nota* Schneider, *D. acuta* Mischina, *Gerdalia dactyla* Belousova, *Bogdoella delicata* (Starojilova), *B. antiqua* Starojilova.
Charophytes: various *Porochara* and for the first time *Auerbachichara*.
Conodonts, conchostracans, plants, spores and pollen.
The Enotajevskaya suite. 57 m of grey and variegated sand-clays with charophytes (*Porochara* and *Vladimirella*) and ostracods dominated by *Gerdalia* (*Gerdalia dactyla* zone).

Laterally the Akhtubinskaya and Bogdinskaya suites (Table 1) are generally combined in a clay unit of 400 m thick. On the eastern border, the Akzarsajskaya suite overlays it in conformity and is represented by red sand clays up to 150 m. On the outer edges, to the north, the Krasnokutskaya suite consisted of sandstones following by clays (273 m) and to the west the Berezovskaya and Lipovskaya (or only Lipovskaya) suites (0-256 m) are transgressive and overlay the Permian or Upper Carboniferous. All these suites are referred to the Baskunchakian horizon.
The correlations could be well-established between Baskunchakian horizon and synchronous deposits of the Russian Platform by fishes (Minikh & Minikh 1997). The fauna of *Parotosuchus* is found also in the sections of Volgo-Uralian anticline, Preuralian and Pripyat throughs, Moscow and Mezensk synclines and in

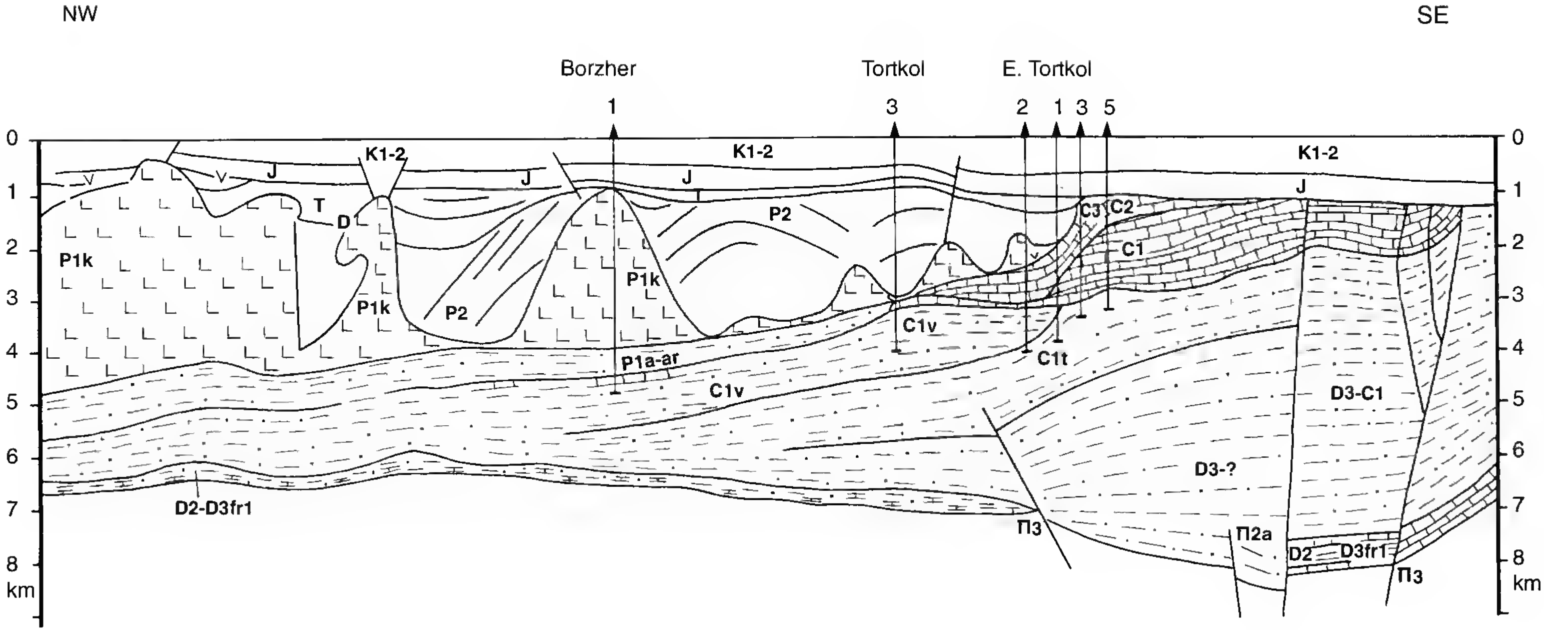

FIG. 4. — Geological-geophysical cross section GG 051 (location on Fig. 7). South-eastern part of Precaspian Depression. Legend: see Fig. 2.

the variegated sandstone of German basin. The ammonites *Dorikranites* and *Tirolites* allow to correlate with the upper Olenekian of Russia and with the Campile beds of Alpine Triassic and the Spathian Tirolites zone (Shevyrev 1990).

MIDDLE TRIASSIC (T_2)
The Akmajskaya and the lower Aralsordkaya series are attributed to the Middle Triassic (Table I).

The Akmajskaya series
It is distributed in most part of the Precaspian Depression. The basal boundary is marked by the change of the Baskunchakian clay in the sandstones of the Middle Triassic. Two suites are recognised: the Eltonskaya and the Inderskaya (Fig. 9).

The Eltonskaya suite (T_{2el}). It begins with sandstones followed by clays and limestones. The total thickness varies from 100 to 400 m.

The lower part, terrigenous, contains the transitional complex with mainly Lower Triassic species and few Middle Triassic species (*Darwinula recondita* Schleifer, *D. lauta* Schleifer, *D. acmayica* Schleifer, *D. postinornata* Schleifer, *Suchonella flexuosa* Starojilova from the *Darwinula lauta* zone).

The upper part, clay and carbonates, is typical from the Middle Triassic (*Lutkevichinella involuta* Schneider, *L. bruttanae* Schneider, *L. minora* Starojilova, *Pulviella ovalis* Schneider, *Triassinella gubkini* Schleifer, *Clirocypris vasilievi* Schleifer, forming the *Lutkevichinella bruttanae* zone).

The Eltonskaya suite contains tetrapods as *Plagioscutum ochevi* Shishkin, Capitosauridae, referring to *Eryosuchus* which is well correlated with fauna of Central Europe (Shishkin & Ochev 1992).

The Inderskaya suite (T_{2in}). It presents clays and carbonates on a thickness of 100 to 250 m.

Both suites (Eltonskaya and Inderskaya) are characterised by a single Middle Triassic Darwinulocopida ostracods assemblage (*Darwinula obesa* Schleifer, *D. kiptschakensis* Schleifer, *D. lenta* Schleifer, *D. lauta* Schleifer, *D. recondita* Schleifer, *D. acmayica* Schleifer) but by different Cytherocopina ostracod assemblages. In the lower suite, there are *Glorianella inderica* Schleifer, *Renngartenella distincta* Starojilova, *Cytherissinella orispa* Schleifer from the *Glorianella inderica* zone. In the upper suite, the following species from the *Pulviella aralsorica* zone occur: *Pulviella aralsorica* Schleifer, *P. obola* Schleifer, *P. lubimovae* Schleifer, *P. directa* Starojilova, *P. marinae* Starojilova, *Speluncelia auerbachi* Schleifer, *S. spinosa* Schneider, *Inderella usunica* Schleifer, *Aralsorella uralica* Schleifer. Moreover, there are bivalves and gastropods *Unionites fassaensis* (Wissmann), *U. muensteri* (Wissmann), *Cryptonerita elliptica* Kittl, *Actaeonina mediocalcis* Hohenstein, vertebrates *Mastodonsaurus torvus* Konzhukova, *Plagioscutum caspiense* Shishkin, which allow the correlation with the lower Keuper of the Central Europe (Shishkin & Ochev 1992).

To the south-western part of the Depression, the Akmajskaya series presents mainly clays and the thickness grows up to 1200 m. To the west, on the borders, it changes in variegated terrigenous deposits of the Morovovskaya suite (275 m) with charophytes, ostracods and in some layers Cytherocopina of Inderskaya suite. To the east, the Akmajskaya suite is completely replaced by the variegated sand-clay Tashijskaya suite (T_2ts; 230 m; Fig. 3) with characteristic non-marine ostracods and charophytes. Outside of the Depression to the north and to the east, the Middle Triassic is missing.

The Aralsorskaya p.p.
This series contains grey to variegated terrigenous and calcareous deposits from Middle and Upper Triassic (Figs 11, 12). The Lower Jurassic Besobinskaya suite overlays it with important uncorformity (Shelechova *et al.* 1989). The Aralsorian is subdivided in six suites: Masteksajskaya, Almamyskaya, Chodinskaya (the three from the Middle Triassic), Koktinskaya, Shalkarskaya and Kusankudukaya (the three from the Upper Triassic).

The Masteksajskaya suite (T_{2ms}). It is composed of grey to black clays, aleurolites, rarely sandstones and limestones (210 m). It overlies the Akmajskian series (*Pulviella aralsoria* zone). Its red analogous deposits extend to the east through

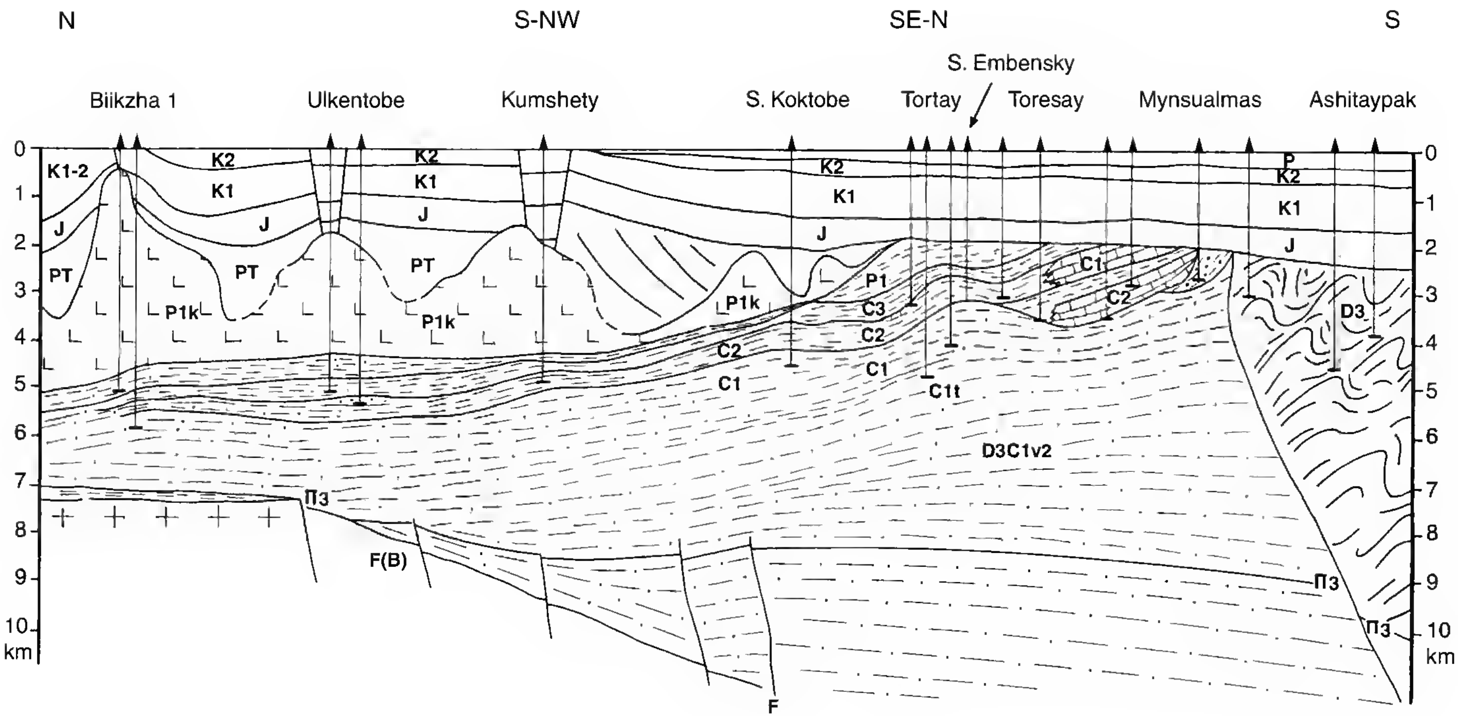

FIG. 5. — Geological-geophysical cross section GG 042 (location on Fig. 7). South-eastern/Eastern part of Precaspian Depression. Legend: see Fig. 2.

the boundaries of the Depression to the Donetz Through and the Pre-Ural. The suite is characterised by a rich ostracod assemblage where the species known in the underlying levels (*Darwinula lauta* Schleifer, *D. obesa* Schleifer, *D. infera* Schleifer, *D. kipschakensis* Schleifer, *Pulviella aralsorica* Schleifer, *P. obola* Schleifer, *P. directa* Starojilova, *Speluncella spinosa* Schneider) are associated with species occurring for the first time [*Gemmanella schweyeri* Schneider, *G. magna* Kozur, *G. grammi* Kozur, *G. movschovichi* Kozur, *G. densistriata* Kozur, *G. meyevi* Kozur, *G. tuberculata* Schleifer, *Speluncella ascedens* Diebel, *Cytherissinella okrajantci* Schleifer, *G. sokolovae* Schneider, *Glorianella efforta* (Glebovskaya), *G. mirtovae* Schneider, *Renngartenella auerbachi* Schneider, *Casachstanella shungayica* Schleifer, *Telocythere fischeri* Kozur, *Lutkevichinella pseudopusilla* Kozur].

The Almamyskaya suite (T_{2ak}). It is represented by grey and variegated terrigenous rocks (0 to 425 m) with Middle Triassic ostracods (*Gemmanella schweyeri* Schneider, *Pulviella ovalis* Schneider, *Speluncella spinosa* Schneider, *S. elegans* (Beutler & Grund), *Glorianella mirtovae* Schneider, *G. efforta* (Glebovskaya), *Renngartenella avdusini* Schneider, *Cytherissinella okrajantci* Schneider, *C.* cf. *elongata* Schneider, *Casachstanella shungayica* Schleifer, *Darwinula* sp.) and miospores.

The Chodinskaya suite (T_{2ch}). It is divided in two parts (Shelechova *et al.* 1988). The lower part is massive (Khodinskaya *s.s.*) and the upper part, which lies with unconformity, is the Khodinskaya suite. In the west, the Barmantsakskaya suite (Movshovich 1994) is equivalent to the Khodinskaya suite *s.s.* These suites are composed of grey and variegated clay, with interbeds of aleurolites, sandstones with sidetite concretions and vegetal crumbs. In the north-east of the Depression, there are some coal interlayers. The thickness varies from 0 to 304 m. In the Barmantsakian suite, there are Middle Triassic ostracods (*Cytherissinella schleiferae* Starojilova, *Darwinula acmayica* Schleifer, *Suchonella* ex gr. *flexuosa* Starojilova, *Speluncella* ex gr. *spinosa* Schneider, *S.* ex gr. *alata levis* Kozur), as well as foraminiferas and charophytes. It can be note

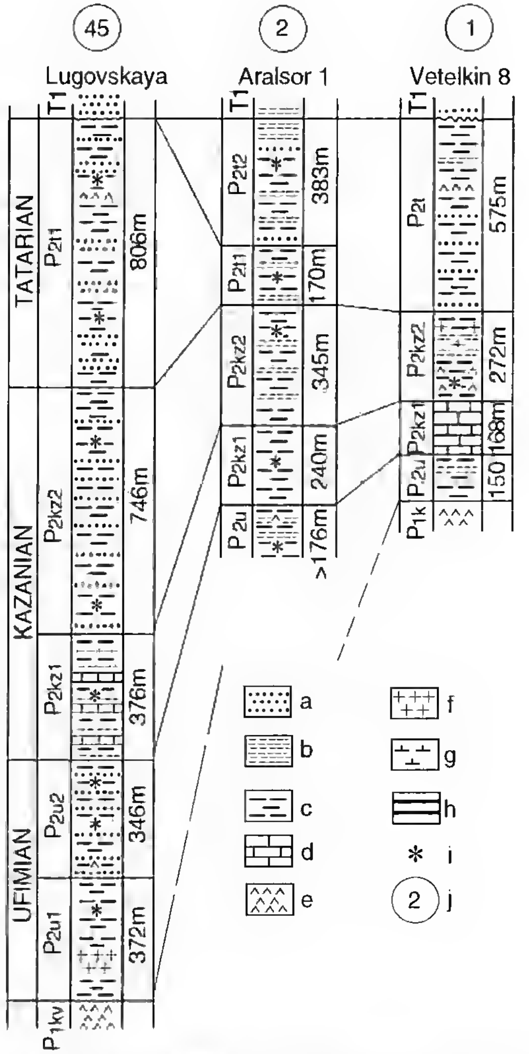

FIG. 6. — The Upper Permian of the Precaspian Depression illustrated by some representative boreholes (Lugovskaya 1, 45 on Fig. 7; Aralsor 1, 2 on Fig. 7; Vetelkin 8, 1 on Fig. 7). Legende: **a**, sand, sandstone; **b**, siltstone; **c**, shale; **d**, limestone; **e**, anhydrite; **f**, salt; **g**, carbonated shale; **h**, coal; **i**, red rocks; **j**, number of boreholes on palaeogeographic maps (Figs 7, 10, 12).

that *Speluncella alata levis* is related to the German basin at the top of upper ceratitic beds (Ladinian) (Kozur 1973).

The only section of the Aralsorian Middle Triassic series is present in the Zabutunian trough in the south of the Depression where 1200 m of sand-clay deposits with some interbeds of limestones [with ostracods as well as pelecypods *Triganodus*

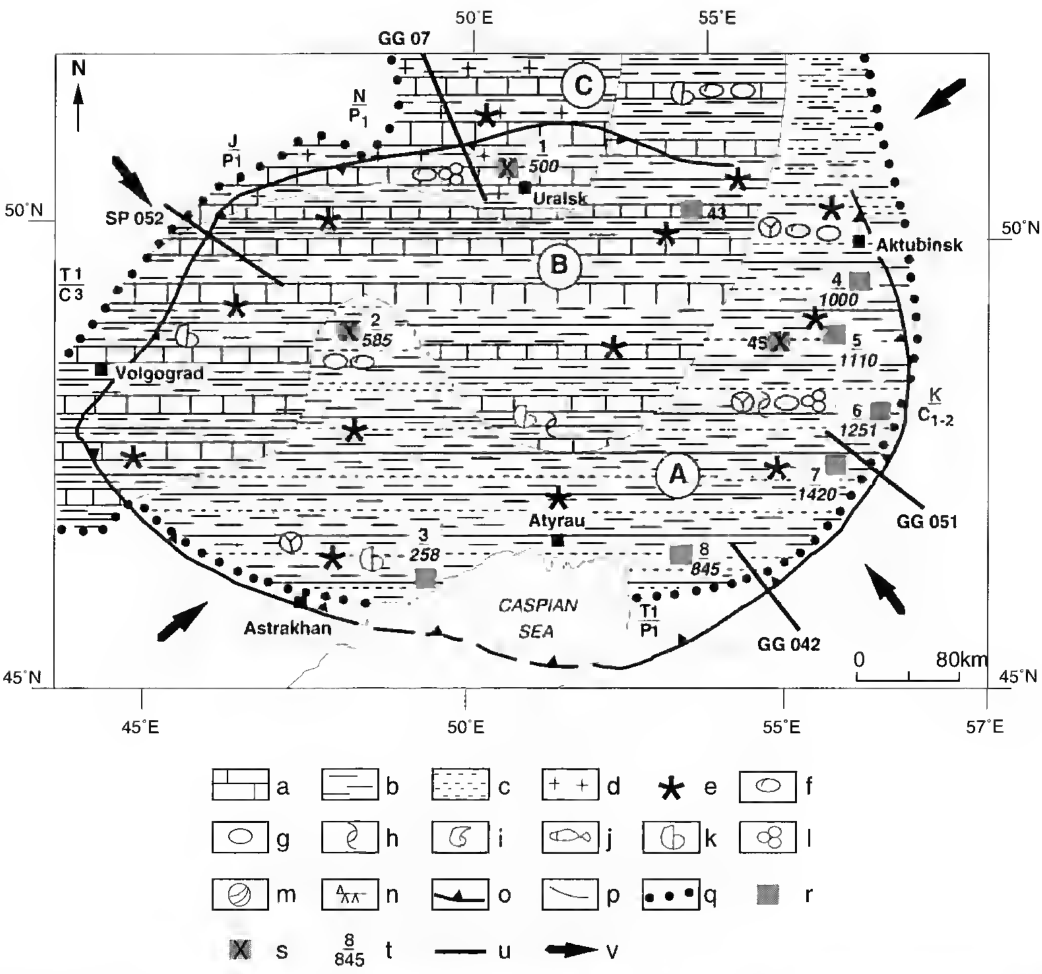

FIG. 7. — Kazanian lithological and palaeogeographical scheme of the Precaspian Depression. **A**, alluvial plain episodically flooded by the sea; **B**, **C**, area of marine (during lower Kazanian-kz1) and lacustrine (during upper Kazanian-kz2) carbonate-clastic (**B**) and salty carbonate (**C**) deposits. Legend for all the palaeogeographic maps: **a**, carbonates; **b**, shales, **c**, sandstones; **d**, salt; **e**, redding; **f**, marine ostracods; **g**, non-marine ostracods; **h**, pelecypods; **i**, cephalopods; **j**, fishes; **k**, brachiopods; **l**, foraminiferas; **m**, charophytes; **n**, vertebrates; **o**, Precaspian Basin boundaries; **p**, limits of lithological-palaeogeographical domains; **q**, limits of recent deposit abundance; **r**, boreholes; **s**, boreholes figured on figs 6, 8, 9, 11; **t**, number of boreholes (in the upper part number of the borehole; in the lower part, in italic, thickness); **u**, cross section of Figs 2-5; **v**, direction of detritical supplies. List of boreholes: **1**, Vetekin; **2**, Aralsor; **3**, Zhambay ; **4**, Sambay ; **5**, Karabulak ; **6**, Kokzhide ; **7**, Mujunkum ; **8**, Kulsary ; **43**, Linevka ; **45**, Lugov.

(?) *praelongus* Kiparisova, *T. sandbergeri* Alberti, *Schafhaeutlia silesiaca* Assmann, *Myophoriopsis gregaroides* (Philippi)] are drilled.

UPPER TRIASSIC (T_3) = ARALSORSKAYA SERIES *p.p.* *The Koktinskaya, Shalkarskaya and Kusankuduk-skaya suites*

The Upper Triassic part of the Aralsorskaya series lies with unconformity on Triassic or Permian.

The Koktinskaya suite (T_{3kk}). It is composed of sand-clay deposits (0-124 m) in the Aralsor, Kusankuduk and Prorvin troughs (respecrively central, eastern and south-eastern parrs of the Depression; Table 1, Fig. 11). Shelechova (1988) described two palyno-complex *Chasmatosporites-Podosporites* and *Camarozonosporites-Gibeosporites*. The first one is described in the transitional interval of Middle-Upper Triassic and the second is characteristic of the middle and upper Keuper of the German Basin, the Carnian-Rhaetian

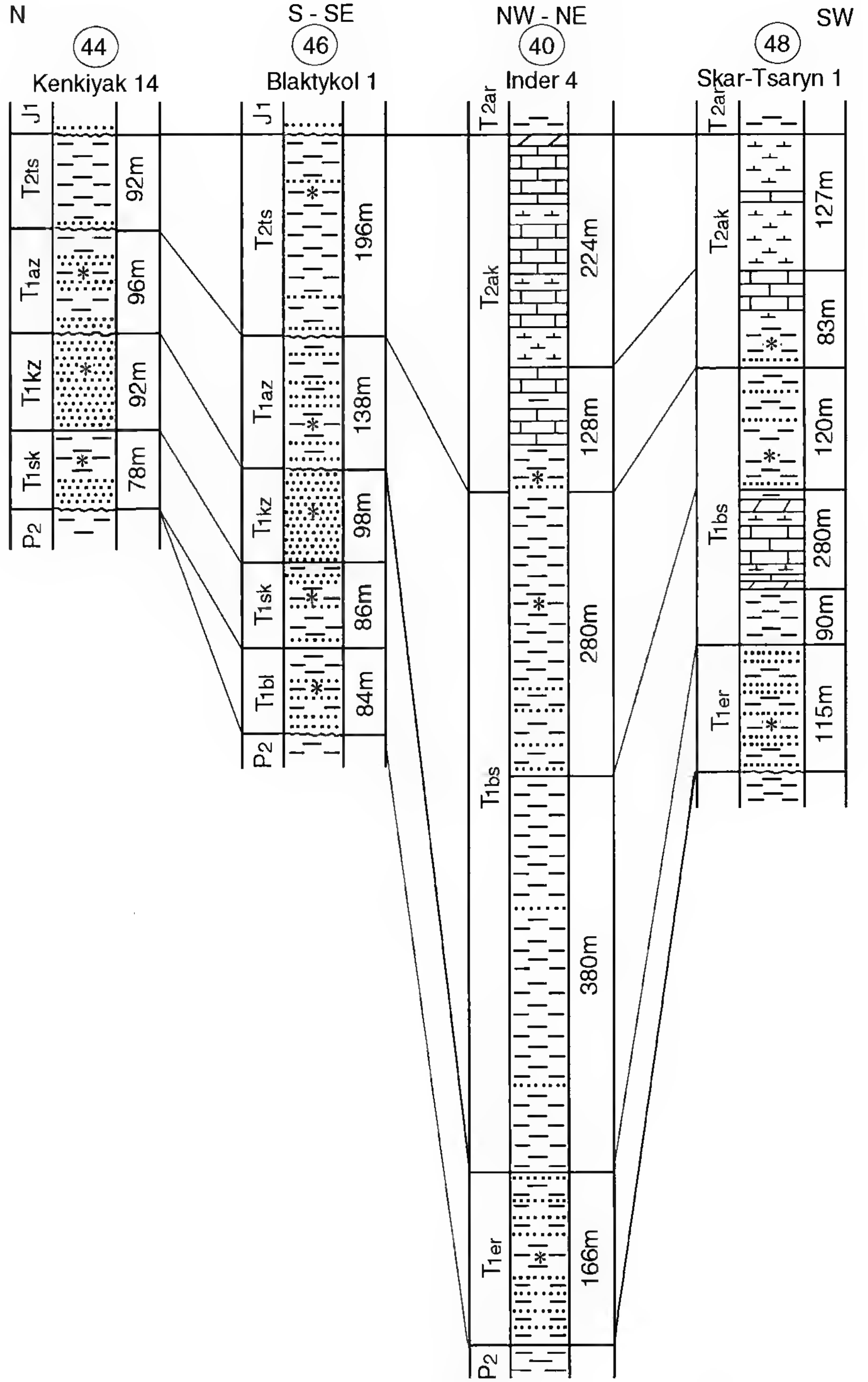

FIG. 8. — The Lower and Middle Triassic of the Precaspian Depression illustrated by some representative boreholes (Kenkiyak 14, 44 on Fig. 12; Blaktykol 1, 46 on Fig. 12; Inder 4, 40 on Fig. 12; Skar-Tsaryn 1, 48 on Fig. 12). Legend: see Fig. 6.

deposits of the Eastern Alps, Caucasus and Donbas (Shelechova *et al.* 1988).

The Shalkarskaya suite (T_{3sh}). It has also a sandy clay composition (Table 1, Fig. 11). Sandstones predominate in the lower part and clays in the upper part. The thickness varies from 0 (area between the Ural and Volga rivers, western and northern borderlands of the Depression) to 84-228 m to the east. Different fossils are recognised: leafprints of *Clathropteris meniscoides* Brongniart (Carnian-Liassic) and palyno-complex *Neoraistrickia taylorii-Gibeosporites* (Carnian), Late Triassic conchostracans *Lioestheria kidoi* (Kobayshi), *L. shimamurai* (Kobayshi), *Pseudestheria (Sphaeropsis) tanii* (Kobayshi), *P. turkestanica* Novojilov & Kapelka, *P. gissarica* Novojilov & Kapelka, *Sphaerestheria koreana* (Ozawa & Watanabe), *Glyptoasmussia madygenica* Novojilov & Kapelka, *Laxomicroglypta kobayashi* Novojilov & Kapelka, *Limnadia gontsharovi* Kapelka, *Liograpta tonsinensis* Novojilov.

The Kusankudukskaya suite (T_{3ks}). It is composed of sandstones, aleurolites, clays, mainly grey with some layers reaching 12-16 m (Table 1, Fig. 11). The total thickness is 0-300 m. The Rhaetian age of the suite is clearly established on miospores (Kukhtinov 1984): presence at the bottom of *Zebrasporites laevigatus* Schelechova, *Z. interseriptus* (Thiergart) Klaus, which are usually absent in Norian. The Norian-Rhaetian palyno-complex *Kyrtomisporites-Zebrasporites* is described by Schelechova *et al.* (1988). These authors showed that the Kusankudukskaya suite is absent in the ultra-deep Aralsor well (Fig. 4), in the central part of the Depression. So, it appears that the Kusankudukskaya suite and the Upper Triassic are absent from the most part of the western half of the Depression. Between the Ural and Emba rivers lower courses (Kukhtinov 1984), the Middle Triassic part of the Aralsorskaya series is missing and the Akmajskaya series (or Older Triassic) are overlay by Upper Triassic (about 220 m). Here, the Permo-Triassic series is more tectonically deformed than in other areas of the Depression. To the south (Prorva area) the analogues of the Akmajskaya have important thickness (to 407 m), more regular structure and display marls within sandy clays. Outside of the Depression, to the north, to the west and to the east, the Akmajskaya series is not subdivided as well as the underlying Akmajskaya series. The overlying Jurassic begins here only in the middle Bajocian.

PALAEOGEOGRAPHY OF THE PRECASPIAN DEPRESSION DURING LATE PERMIAN AND TRIASSIC

We are looking here to the Precaspian Depression and its adjacent areas. This territory is located at the south-eastern part of the Russian platform bordered by the Uralian and Donets-Ustjurt Hercynides. The palaeogeography is controlled by tectonic and climatic changes (from high arid during the Kungurian, to arid during the Late Permian and Early Triassic and humid during Middle-Late Triassic). The growing of salt domes during the Ufimian has significant influence on the deposional conditions.

Taking in account all the sections of the Upper Permian in the south and east of the basin, there is no significant lithological changes at the series boundaries.

The base of the Ufimian is represenred by grey sediments. The red coloration increases little by little when we going up in the series. The presence of sulphate inclusions and of halogenous rocks (in some places) can be attributed to the development of the Ufimian basin and residual salt lakes; the geochemistry of the Kungurian and Ufimian (Solikamian) are very similar (Kukhtinov 1984). The main change occurs during Sheshmian. The progressive disappearance of the Kungurian salt-bearing sea takes place. The presence of grey sediments, vegetal debris and autigenic pyrite prove the restorarion of normal depositional environments.

The Urals is the basic source of debris. The debris size and sand fraction content of the rocks increase to the east (Dmitrievskij 1966). The mineral composition of the Upper Permian dettiral fractions is characterised by feldspathic graywake association and is represented by quartz (20-35%), feldspar (15-32%), fragments of effusive and carbonates rocks (45-48%) and rarely of metamorphic rocks (2-5%). In the central part of the basin, the quartz content increases.

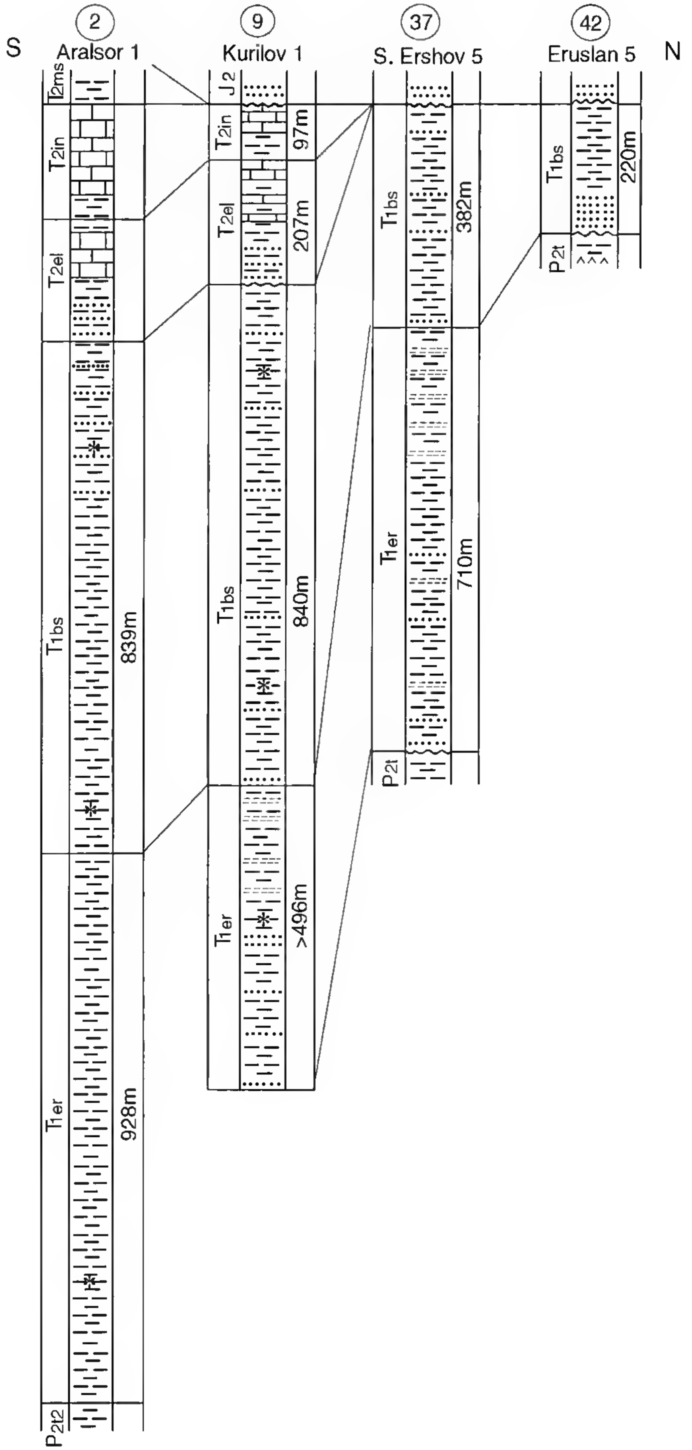

FIG. 9. — The Lower Triassic of the Precaspian Depression illustrated by some representative boreholes (Aralsor 1, 2 on Fig. 10; Kurilov 1, 9 on Fig. 10; South Ershov 5, 37 on Fig. 10; Erulsan 5, 42 on Fig. 10). Legend: see Fig. 6.

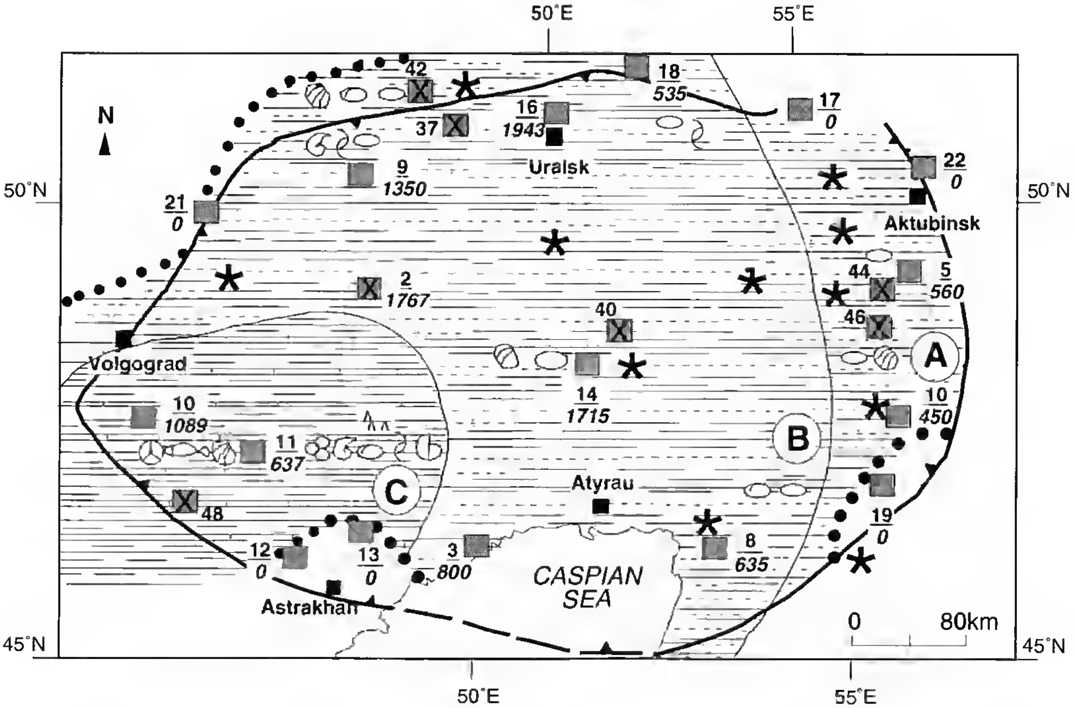

FIG. 10. — Lower Triassic lithological and palaeogeographical scheme of the Precaspian Depression. **A**, area of alluvial and proluvial deposits; **B**, alluvial plain, flooded episodically by the sea; **C**, epicontinental marine deposits. Legend: see Fig. 7. List of boreholes: **2**, Aralsor; **3**, Zhambay; **5**, Karabulak; **8**, Kulsary; **9**, Kurilov; **10**, Sadovaya; **11**, Bugrin; **12**, Stepnov; **13**, Zavolzh; **14**, Ushtobe; **16**, Chinarev; **17**, Mertvye Soli; **18**, Akzhar; **19**, Tuskum; **21**, Nikolaev; **22**, Podgornen; **37**, Ershov; **40**, Inder; **42**, Eruslan; **44**, Kenkiyak; **46**, Biaktykol; **48**, Shar-Tsaryn.

The second half of the Ufimian is defined by the accumulation of red sediments. The red coloration is conditioned by increase of aridity entails by wide development of red eluvium sediments enriched in ferrigenous pigment. This is the result of Fe deposition in clay minerals of montmorillonite and illite groups. The hydration degree of ferric oxides and the intensity of ochre increasing in eluvium are defined by temperature. It is not accidentally if the red coloration is developed in the arid steppes and desert areas of Kazakhstan and develop a brown coloration to the north. The coloration of rocks is defined by the Fe^{3+}/Fe^{2+} ratio (Janov 1956): with a value up to 3 it is red-brown to brown-red, between 1.6 and 3 it is violet to red-brick, lower than 1.6 it is green-grey to grey, 0 is black.

Probably in the basin sedimentation, predominance of oxidation conditions contributes to the preservation or subsequent increase of red coloration in the sediments. The oxidation conditions are confirmed by the low content of organic remains. The non marine bivalves and ostracods (Darwinulacea, which are representative of 2-3 m water deep, no more than 10 m) give evidence of the basin shallowness. On shore areas, in estuaries, the colonial algae (cyanophyceae) wide development in Aktubinsk Pre-Ural and probably in Precaspian Depression proves this assessment. In the miospore complex, the allochtonous elements come from conifers grown on the high lands.

During the Ufimian, the uplift of destruction areas and the development of salt domes begin in the trough. At the same time, in the depressions between the salt domes, syn-sedimentary lakes appear quite often, due to the washing of salt by underground waters. Such sedimentation takes place now in Inder Lake. The sedimentation in

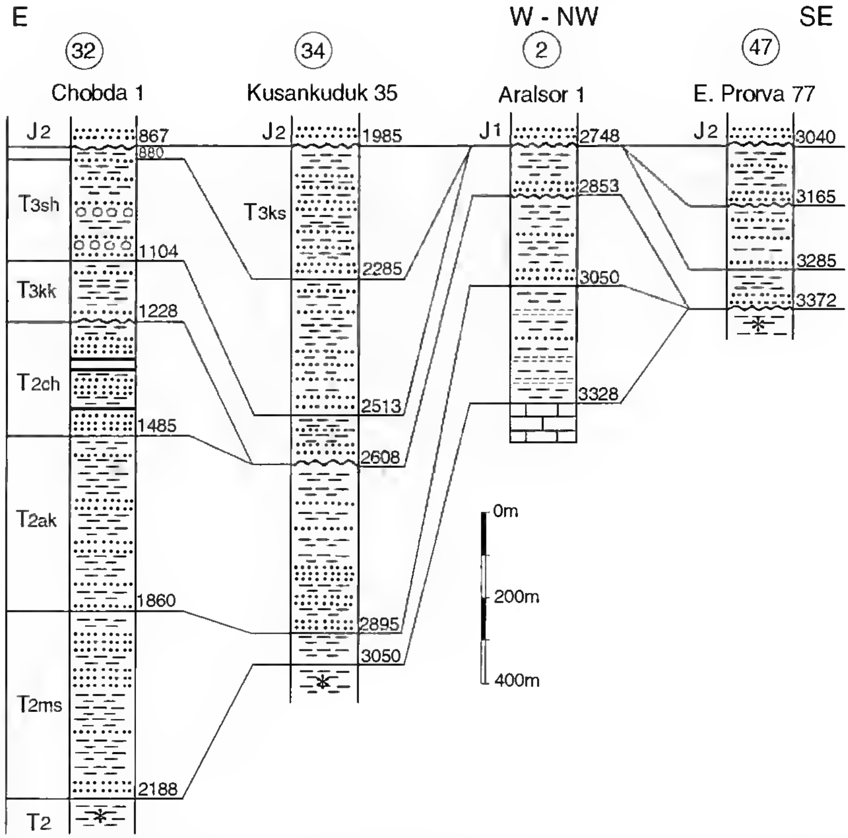

FIG. 11. — The Middle and Upper Triassic (Aralsorskaya suite) of the Precaspian Depression illustrated by some representative boreholes (Chobda 1, 32 on Fig. 12; Kusankuduk 35, 34 on Fig. 12; Aralsor 1, 2 on Fig. 12; East Prorva 77, 47 on Fig. 12). Legend: see Fig. 6.

the basin is controlled by difference between heightening zones (domes) and trough zones (between domes).

The Kazanian (Fig. 7) begins with the boreal sea transgression which follows the Urals to reach the northern Precaspian territory. Thin mainly carbonated rocks with shallow marine fauna (foraminifera, ostracods, bivalves, bryozoas, ...) are developed in the western, central and lesser in the eastern parts of the Depression. In the south (Zhambaj area) the sediments are represented by interbedding red and grey terrigenous sediments with some marine remains. The analogous rocks with marine ostracods were detected between Volga and Ural rivers (Aralsor well). The terrigenous material comes from the south, from Karpinski uplift and its eastern extension, and hinders the carbonate development. From time to time, the sea stretches far to the east, to Kenkijak and Makat (South Emba). Between red rocks, the interbeds of grey sediments contain foraminifera, crinoids and radiolarians (Kukhtinov 1984).

In the eastern part of the Depression, as far as its present boundary, an alluvial plain spreads out and, from time to time, is flooded by the sea. A thick sequence of aleurolite and argilite which contains only one bed of limestone, corresponds here to the marine limestone deposits. Fine detritic material is accumulated in the lakes without flow.

During the late Kazanian, the regression is caused by the Uralian orogenic movements. The late Kazanian succession is composed of terrigenous

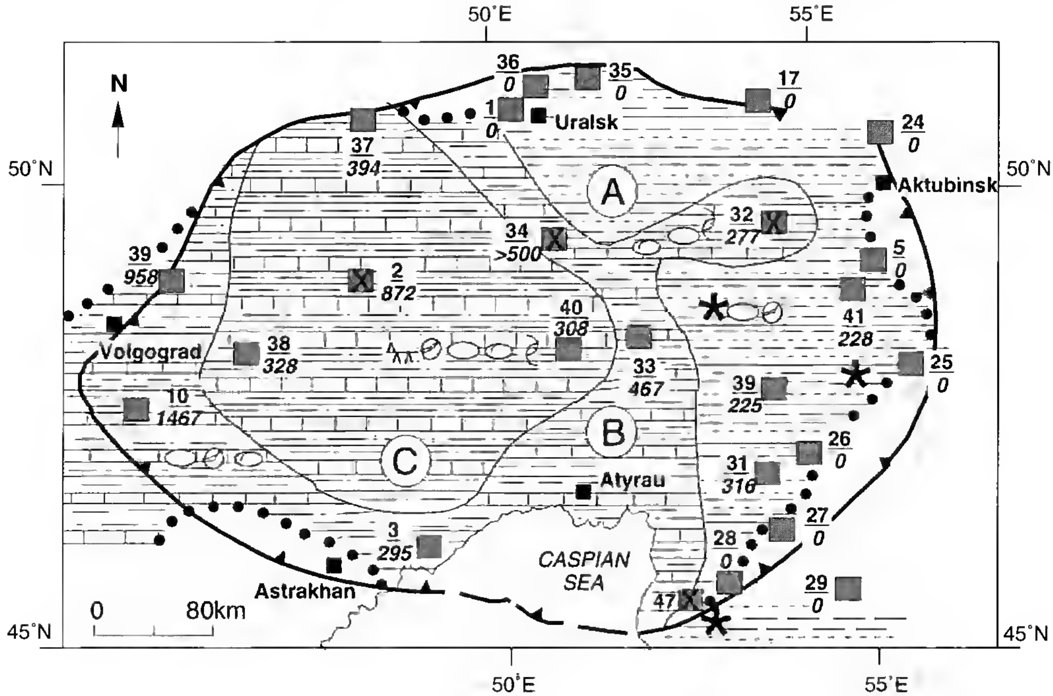

FIG. 12. — Upper Triassic lithological and palaeogeographical scheme of the Precaspian Depression. **A**, alluvial plain, flooded episodically by the sea; **B**, **C**, carbonate-clastic (**B**) and clastic-carbonate (**C**) deposits of shallow epicontinental sea. Legend: see Fig. 7. List of boreholes: **1**, Vetekin; **2**, Aralsor; **3**, Zhambay; **5**, Karabulak; **10**, Sadovaya; **17**, Mertvye Soli; **24**, Jusa; **25**, Zhanazhol; **26**, Chikembay; **27**, Mashly; **28**, Suishbek; **29**, Chumyshty; **31**, Zhusalysay; **32**, Chobda; **33**, Matenkozka; **34**, Kusankuduk; **35**, Pavlov; **36**, Teplov; **37**, Ershov; **38**, Shungay; **39**, Novonikol; **40**, Inder; **41**, Shubarkuduk; **47**, East Prorva.

sediments with coarse detritics including gritstones and conglomerates. These last ones are especially characteristic from the areas surrounding the domes.

In the residual water reservoirs of northern and western parts of the Depression, terrigenous sulphates and halogenous sediments are accumulated. In other areas, the sedimentation is terrigenous with alluvial, lacustrine and deltaic accumulations.

The continental basins contain a rich fauna of crustaceans and bivalves and numerous algae which characterise shallow environment. The salinity is no negligible judging to the Sr/Ba ratio equal to 2.3.

The total thickness of the Kazanian (about 1200 m) on the eastern part of the Depression shows that a large trough is present, compensated by detritic material from the Urals, Mugodzhar and South-Emba uplifts.

The Tatarian is characterised by continental environments. The alluvial North Caspian plain sinks slowly and is filled by sediments from lakes, rivers and temporal water streams. The Sr/Ba ratio falls from 2.3 to 1.3-1.1, this is typical an indicator of brackish water. Major inhabitants are non marine pelecypods, ostracods, algae (charophytes, red, brown, bushy cyanophyceae). The shallow basins are often dried (presence of mud cracks). The frequent cross-beddings are characteristic of the active hydrodynamic regime. The dome are eroded. Remains of Kungurian anhydrite are present in the early Tatarian series. In some places, especially in the south of Aktubinsk Pre-Ural area, the lake deposits are common – chemogenic limestones, clay with abundant organic matter. There are numerous charophytes and small fauna of bivalves.

A proluvial plain spreads out along the Urals area destruction. Detritical fan of temporal flows

reaches the Shubarkuduk area, especially during the late Tatarian. Cross-bedded sandstones of channel and delta types are developed in Kenkiiak and Mortuk areas. The intraformational washing out of the Tatarian is an indication of sedimentation above the basis of erosion (near dome area). The fine grained sand-aleurolite and pelitic material are accumulated in the lakes of the central areas.
In the surrounding emerged lands, there is an almost constant uplift which induces an intensification of erosion and formation of frequent interbeds of detritic material. It obviously takes place during Severodvinian when coarse detritical deposits begin to be widely distributed.

At the end of the Permian, the eastern and southern areas of the Depression are involved in the uplift which entails erosion of accumulated sediments and induces the unconformity of the Triassic on the Permian.

At the beginning of the Triassic (Fig. 10), the sedimentation area is considerably smaller than the Permian one. In fact the structure of the sedimentation basin changed: in the early stages, the major sedimentary layers were located in the eastern part, later they are concentrated in the central part of the Depression. The eastern, southern, south-western and probably northern peripheral parts of the Precaspian Depression were considerably uplifted and represent a baring area. The Tatarian and, sometimes in the south the Kazanian rocks were washed out. At the same time, the central part of the basin was not inverted. This is why the unconformity does occur between Permian and Triassic on the borders.

Slowly, the expansion of the sedimentation basin takes place. The presence of conglomerates and cross-bedded sandstones in the eastern and south-eastern parts of the Depression is due to the development of alluvial and proluvial deposits, step by step transformed into submarine-deltaic and lake deposits (Dmitrijevskij & Proshljakov 1970). In the eastern part of the Depression, channel flows, in the a sublatitudinal direction, cut (Mortuk, Kenkijak, Kokshide) or walk around (Shengelshij) the domes which are uplifted (Pronicheva & Savinova 1980). When the domes are cutting, a wide development of coarse detritics rocks probably caused by the formation of a blind delta is observed. On the whole a piedmont-fan type of detrital material distribution is manifested in this area.
In the central regions, the deposits are represented mainly by fine-grained sands, more often by aleurolites and pelites due to the multiple redepositions and transfers during that time. Therefore, the rocks have high mineralogical (quartz and feldspar content reaches 80-90%) and textural maturity.
The Early Triassic deposits have a high content of epidote in heavy fraction coming from the erosion of metamorphic rocks of Ural and Mugodzhar, following by a rapid burying.
The water reservoirs are mainly fresh water (Sr/Ba = 0.7 – Demchuk *et al.* 1971) with charophytes, ostracods and other crustacean. The presence of mud-cracks, worm activity tracks, and other emphasise the shallowness. Depressions with lack of drainage and salt lake types were well developed.

From the Olenekian, a clear change in climatic conditions takes place. The transgression coming from the south, i.e. from Caucasus and Tethys, induces an increasing of the humidity. The sea covers the south-western part of the Depression; from time to time it widens its boundaries down to the southern periphery and Biikjal, in the east (Fig. 10). At this time, carbonate and sandy clay sediments accumulated here. At first, the basin is connected with Tethys and it contains normal marine fauna – brachiopods, ammonoids, foraminiferas, conodonts, fishes, ostracods with genera of Cypridacea and Cytheracea (*Clinocypris*, *Spinocypris* and especially *Triassinella*). In the South, the ostracods *Bairdia*, *Bairdiacypris* and *Healdianella* are very common. In other times, the basin has poor connections with the ocean. The basin is a slightly salted one (Sr/Ba = 0.9). The fauna is represented by ostracods, bivalves, gastropods, worms, fishes and charophytes. Along the coasts, the xerophytes of *Pleuromeia* and Lycopodiacea type are growing. The coast lands are flat-hilly plain, alluvial and proluvial sediments settle. Close to the destruc-

tion areas, coarser deposits occur on a piedmont plain. The detrical material comes from the erosion of Urals to the east and from the Voronesh anticline and the Donets fold system to the west and to the south (Movshovich 1977; Janochkina & Startsev 1977). The upward salt domes of Upper Permian are additional source rocks. In Baskunchak and Inder Lakes area, there are relatively coarse deposits formed by drag flows (Movshovich & Tsebenko 1974). The syn-sedimentary uplift of domes leads to the change of the erosional bases and to intraformational washing out in the sections. The tracks as pebble gravel lenses occur especially often in the upper part of the Bashkuchakian series.
Eolian formations are present in the Early Triassic deposits; in sandstones and clays, the quartz grains have characteristic blunt surface and striations.
Sandstones and aleurolites with bad granulometric sorting and heterogeneity of fragmentary grains are due to the different sources of erosion material. The presence of well-preserved Carboniferous rocks in the Lower and Middle Triassic sediments at Matenkozha (left bank of Ural River) suggests that not only the Permian but also the Carboniferous rocks from uplifted surrounding areas are eroded (Kukhtinov *et al.* 1982).
The existed water basins are quite shallow. In rocks, numerous cracks from drying are found, stream bedding and organic remains, adapted to environment with temporary drying-up – amphibians, ostracods, fishes, conchostraceans. Oxidising conditions prevailing here. Only in the middle Olenekian marine basin, with clay and limestone deposits, the environment changes to regenerating. More active processes of chemical erosion take place. Judging to the ostracod distribution, multicoloured and red sediments are formed not only in continental environments but also in the periphery of salty basin.
At the end of the Early Triassic, the sea regresses and continental regime dominates.

The Middle Triassic (Fig. 12) is characterised by a new incursion of the sea and its area of distribution is quite the same than previously. The great change between Lower and Middle Triassic deposits is probably due to ingression along river channels. The normal transgressive sequence – sandstones, clays, limestones – of the Akmajskaya series and variegated terrigenous deposits of the surrounding flatlands are developed. The remains of ostracods, molluscs, fishes and charophytes, not clearly marine, indicate the hindered connection with the ocean. The Stavropol uplift of Northern Caucasus, of Middle Caspian, of Karabogaz and Buzachink domains, the emerged eruptive massifs of Mangyshlak as well as organogenic buildings could be considered as palaeogeographic barriers.
During the second half of the Middle Triassic, carbonate deposits are occasional. Almost everywhere, grey and rarely variegated sands, aleurolites and clays are deposited. The area of distribution is considerably extended outside of the Depression, i.e. into the southern Pre-Ural and Pre-Uralian trough. In the north-eastern part of the Depression, the marine environments are episodically replaced by transitional zones (coastal plains with coal accumulations). Numerous ostracods, including the brachihaline *Gemmanella* genus, are associated with these deposits (Aralsorian series). Single marine euhaline *Bairdia* genus is found with them.
During the Late Triassic, approximately the same situation is preserved. Under a humid climate, there is great abundance of hygrophytes on insular and coastal lands, conifers with fern underbrush and pteridosperms on high lands. In the transitional areas, herbaceous swamps and overgrown lakes are widely developed. In the basin, the conditions are changed time to time into oxidising shallow water environments. The irregular interbedding of sands and clays shows the eustatic movements. The central areas of the Depression subside intensively with important filling. The increase of terrigenous material shows the uplift of emerged areas. The regression continues and the continental environments dominate.

At the end of the Triassic-beginning of the Jurassic, the Precaspian Depression, especially its western part and the adjacent areas, are uplifted and become erosion lands.

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New stratigraphic and palaeogeographic data on Upper Jurassic to Cretaceous deposits from the eastern periphery of the Russian Platform (Russia)

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ABSTRACT
The Late Jurassic and Late Cretaceous were periods when, after prolonged continental erosion, stable marine sedimentation took effect on the Russian Platform. The sediments which accumulated have diverse lithological compositions and a mixture of transient and endemic faunas. Lithological diversity and a wide variety of facies has led to problems in stratigraphical correlation of Late Mesozoic sequences and discrepancies in palaeogeographical reconstructions. Differenr faunal groups belonging to a wide variety of palaeozoogeographic provinces exist within these deposits. Therefore, we use all available microfossils (radiolarians, foraminiferas, nannoplankton) and macrofossil groups (ammonites, buchias, inoceramides) in order to establish the synchronicity of anoxic and other events, to propose biostratigraphic zonations and model the palaeogeography for Late Jurassic: lower Kimmeridgian and middle Volgian as well as Cretaceous time. We suggest that the Peri-Tethys of Eastern Europe is a unique area in which to solve the problem of stratigraphic correlation as it incorporates both Boreal and Transitional to Tethyan palaeoclimatic provinces.

KEY WORDS
Jurassic,
Cretaceous,
stratigraphy,
ammonites,
radiolarians,
foraminifera,
nannofossils,
palaeogeographical map.

RÉSUMÉ
Nouvelles données stratigraphiques et paléogéographiques sur les dépôts jurassiques et crétacés de l'extrémité orientale de la Plate-forme russe (Russie).
Le Jurassique supérieur et le Crétacé forment une période où, après une longue érosion continentale, une sédimentation marine stable s'installe sur la plate-forme russe. Les sédiments accumulés ont des lithologies variées et présentent un mélange de faunes endémiques ou transitionnelles. La diversité lithologique er la grande variété de faciès ont rendu complexes les corrélations stratigraphiques pour ces séries du Mésozoïque tardif et ont même créé des désaccords dans les reconstitutions paléogéographiques. Différents groupes fauniques, appartenant à une grande variété de provinces paléobio-

géographiques existent dans ces dépôts. De ce fait, nous avons été conduits à utiliser tous les groupes disponibles de microfossiles (radiolaires, foraminifères, nannoplancton) et de macrofossiles (ammonites, buchias, inocéramides) afin d'établir le synchronisme des événements, anoxiques ou autres, pour proposer des zonations biostratigraphiques et des modèles paléogéographiques pour le Jurassique supérieur : Kimméridgien inférieur et Volgien moyen ainsi que pour le Crétacé. Nous pensons que la partie péri-téthysienne de l'Europe orientale est un endroit unique pour résoudre les problèmes de corrélation stratigraphique puisqu'il incorpore des éléments fauniques de provinces boréales et de la transition vers les provinces paléoclimatiques téthysiennes.

MOTS CLÉS
Jurassique,
Crétacé,
stratigraphie,
ammonites,
radiolaires,
foraminifères,
nannofossiles,
carte paléogéographique.

INTRODUCTION

Our research team has undertaken field work in Volga River Basin (August 1995, members of field work team were as follow: E. Baraboshkin, N. Bragin, E. Lambert, V. Vishnevskaya, G. Zukova; August 1997, V. Vishnevskaya, G. Zukova) and in the Timan-Pechora Basin (September 1995, A. Kostyuchenko, G. Sedaeva, V. Vishnevskaya). All previously published and unpublished data concerning of these regions were revised and taken into account.

The aim of our field trips was to collect precise and well-located samples with fossil material in order to establish accurate biostratigraphical correlations and to propose palaeogeographic reconstructions which could provide a basis for modelling of palaeogeographic maps.

During the field work, we investigated and sampled the following areas in detail: (1) Kimmeridgian-Volgian portion of the standard Gorodische Section of Volga River Basin and Ukhta outcrop as well as 21 outcrops and 52 boreholes of the Volga-Kama and Timan-Pechora Basin (Figs 1-5); (2) middle Volgian-Hauterivian sections near Gorodische and New Berdianka villages (Figs 2, 3); (3) Aptian-Albian sections from boreholes of the Penza region (10 km of Penza town, west of Volga River); (4) Barremian-Turonian section to the north of Uljanovsk city; (5) Cenomanian-Maastrichtian sections near Shilovka settlement (50 km south of Uljanovsk city).

MAIN LITHOFACIES AND STRATIGRAPHY OF THE KIMMERIDGIAN

The lower Kimmeridgian is represented by organic shale (Fig. 5, borehole 18) with clay (Fig. 5, boreholes 15-17, 19, 20, 22, 23, 25-27), glauconitic sandstone, aleurolite (almost equivalent to silt-stone in Russian literature) and clay (Fig. 5, boreholes 24, 28), and micrite in the outcrops of the Ukhta section. Rare phosphatic pebbles and pyritic concretions were also found.

The time interval investigated corresponds to the early Kimmeridgian in terms of standard ammonite zonation for the Boreal Realm of the Russian Plate. Within the Barents-Pechora area, the *Amoeboceras ravni* zone and in the Volga-Kama-Oka Basin, the *A. kitchini* zone are present. Other characteristic ammonites are *Rasenia trimera* Oppel and *R. stephanoides* Oppel.

Kimmeridgian strata, which yielded radiolarians (Kozlova 1994; Vishnevskaya 1997), are well represented in the Timan-Pechora Basin. The Pechora-Volga sedimentary basin was probably produced by a Late Jurassic phase of rifting (Kostiuchenko 1993), and was filled with radiolarian-bearing clay and shale deposits in a sub-platform environment.

The Kimmeridgian clay of Pechora and Ukhta regions is also rich in glauconite and montmorillonite. Glauconite (15-30%), montmorillonite (10-30%), hydromica (10-30%) and chlorite (5-10%) are the dominant components in Kimmeridgian bituminous clay whereas glauco-

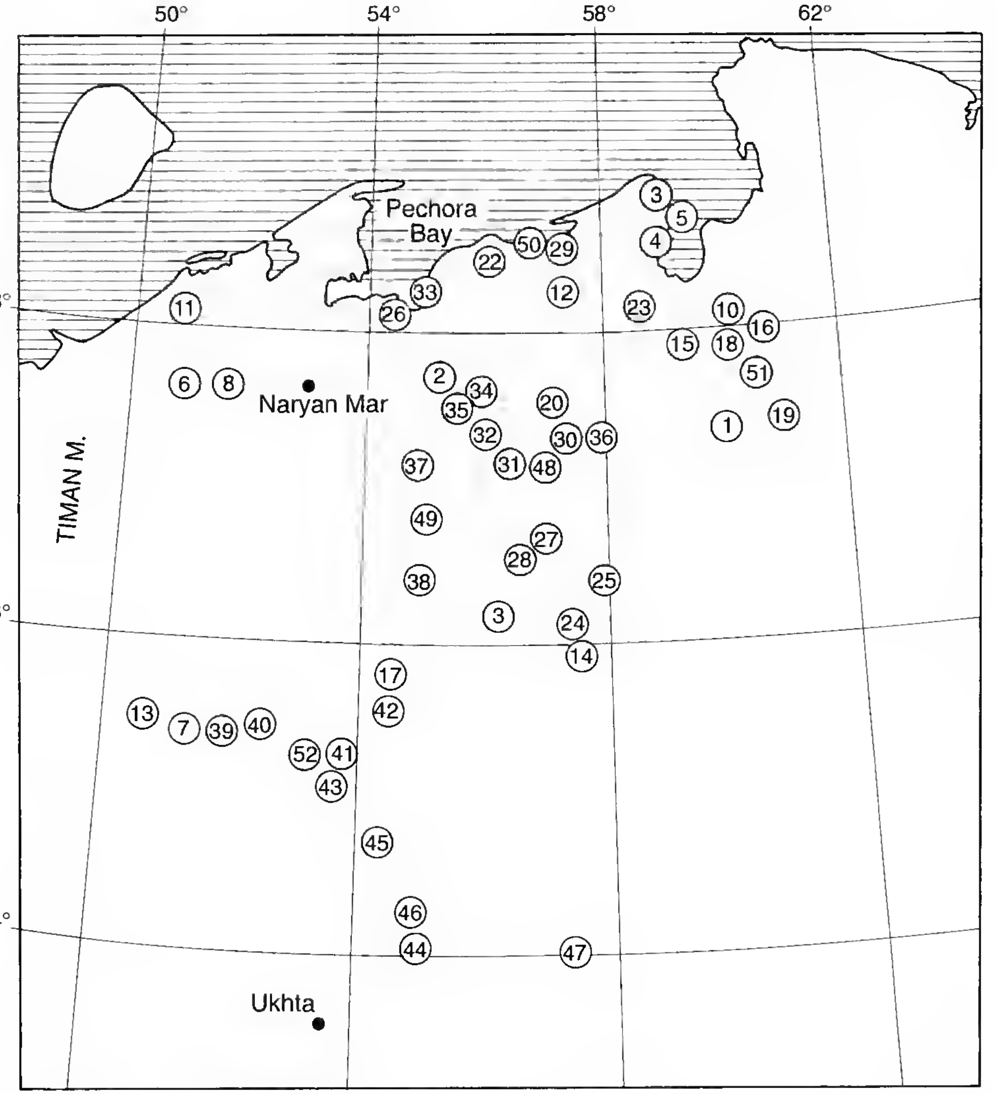

FIG. 1. — The location of investigated boreholes and outcrops of Timan-Pechora Basin (the numbers correspond to their official record).

nite (30-40%), kaolinite (25-30%), and montmorillonite (20-30%) predominate in the organic-rich Volgian shale.

The Kimmeridgian clay (5-45 m) from the Pechora and Ukhta regions has a conformable stratigraphic contact with the underlying strata (Fig. 5) and demonstrates a succession of transgressive and regressive characters up to Volgian strata.

Radiolarian taxa make up only a minor part of the total fauna. Practically all taxa present are known in the Boreal province of the Russian Platform and Circum-Pacific Rim. The lower Kimmeridgian radiolarian assemblage of the *Parvicingula vera* zone of the Barents-Pechora-Ukhta region includes: *Archaeocenosphaera inequalis* (Rust), *Praeconocaryomma* ex gr. *sphaeroconus* (Rust), *Pseudocrucella* aff. *prava* Blome, *Crucella crassa* (Kozlova), *C. squama* (Kozlova), *C.* aff. *mexicana* Yang, *Orbiculiforma* cf. *iniqua*

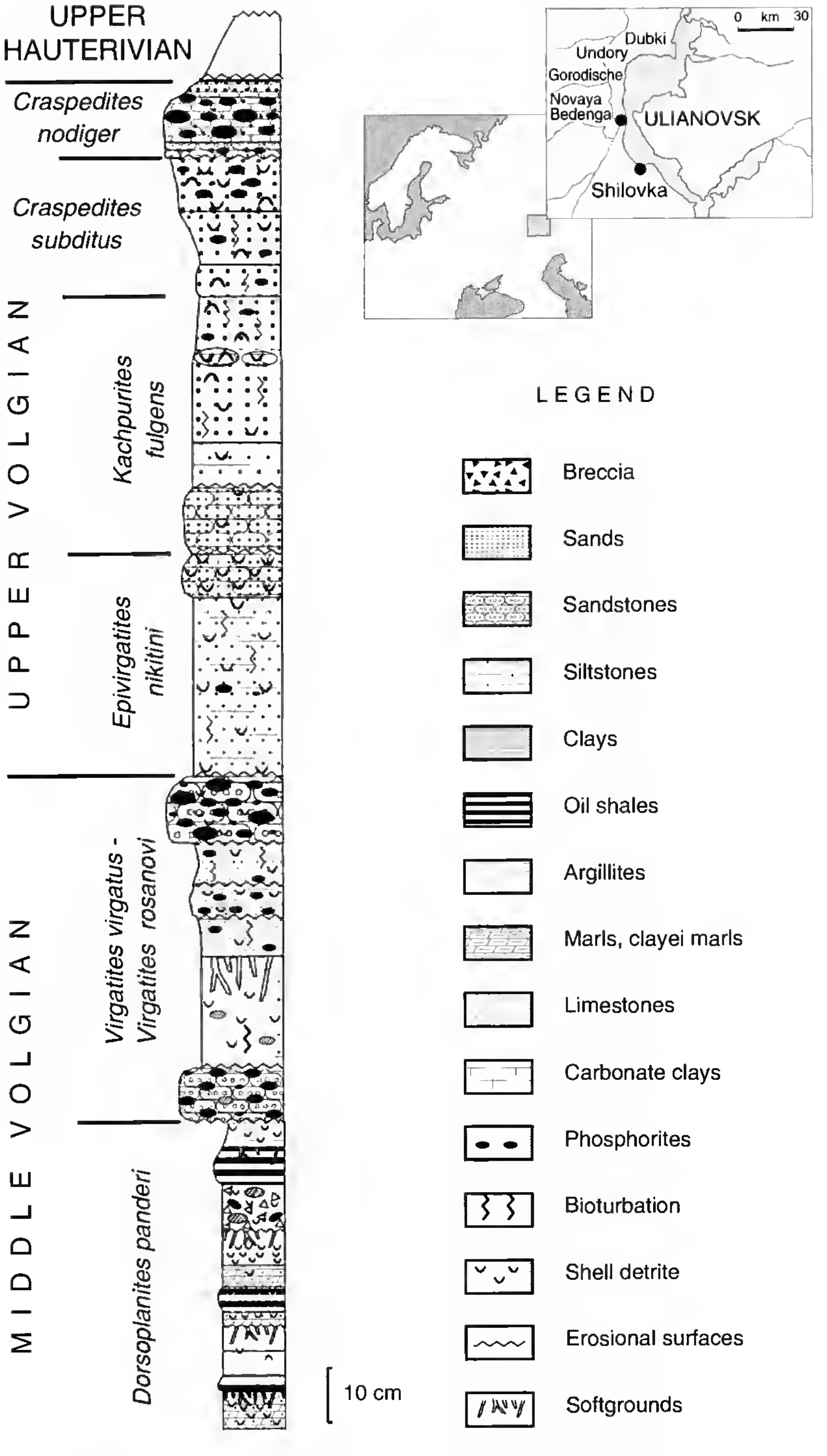

FIG. 2. — The location of investigated sections of Volga Basin and stratigraphic column of the Volgian stage of the Gorodische Section.

Blome, *O.? retusa* (Kozlova), *Pantanellium tierrablankaense* Pessagno & McLead, *Parvicingula inornata* Blome, *P.* cf. *blowi* Pessagno, *P. haeckeli* (Pantanelli), *P. burnensis* Pessagno & Whalen, *P. pizhmica* Kozlova, *P. pusilla* Kozlova, *P. papulata* Kozlova, *P. santabarbarensis* Pessagno, *P.? enormis* Yang, *P.? blackhornensis* Pessagno & Whalen, *Excingula? bifaria* Kozlova.

The lower Kimmeridgian *Parvicingula vera* zone of the Barents-Timan-Pechora Basin (Vishnevskaya & De Wever 1996) is probably equivalent to the lower Kimmeridgian *Crucella crassa* assemblage of Kozlova (1994) and correlates with the *Buchia concentrica* zone, *A. ravni* ammonite zone and *Epistomina unzhensis* foraminiferal zone as well. This interval probably corresponds to the Kimmeridge Clay Hydrocarbon Formation of the North Sea which contains abundant *P. jonesi* (Dyer & Copestake 1989).

A study of *Parvicingula* distribution shows a predominance of this genus in the Kimmeridgian of the Timan-Pechora and Barents regions. Species of this genus are represented by a wide range of morphotypes. The co-occurrence of Arcto-Boreal foraminiferal assemblages together with Jurassic radiolarians and *Buchias* confirms the possibility of using *Parvicingula* as palaeoclimatic indicator (Vishnevskaya 1996). For example, the main Kimmeridgian representatives of the Moscow region are *Parvicingula vera* Pessagno & Whalen, *P. inornata* Blome, *P. elegans* Pessagno & Whalen. Parvicingulides prevail, comprising 50% of this assemblage and in the middle Volgian of the Moscow Basin, are represented by *P. haeckeli* (Pantanelli), *P. hexagonata* (Heitzer) (Bragin 1997).

In the Gorodische Section (Volga Basin) *Parvicingula jonesi* (Pessagno) is the dominant species in the Kimmeridgian and the percentage of parvicingulides in the total radiolarian fauna reaches 50-60%.

Radiolarian-bearing organic black shale and bituminous clay which were deposited in anoxic environments are assigned to the lower Kimmeridgian (*Cymodoce* zone). This interval exhibits black shale layers with a high TOC (more 10%) content and good petroleum potential (Baudin *et al.* 1996). Ammonite horizons containing *P. densicostata* and *P. baylei* can be recognised in the lowermost part of Kimmeridgian of the Gorodische Standard Section (*Baylei* zone of the Standard Scale).

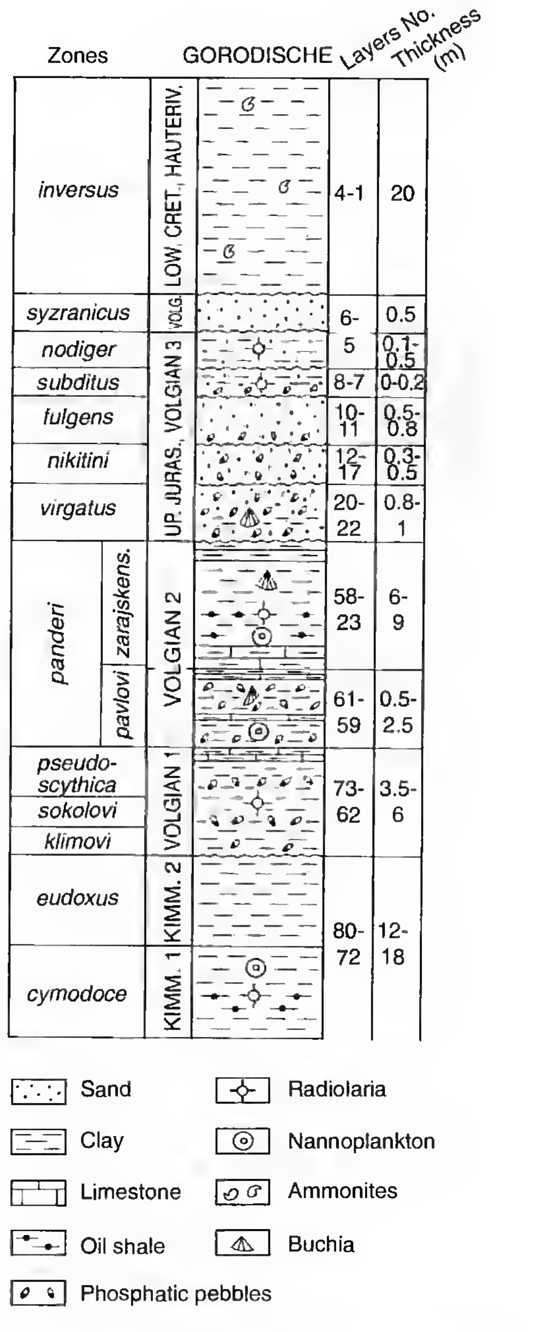

Fig. 3. — Composite column of the Kimmeridgian-Hauterivian stages of the Gorodische Section.

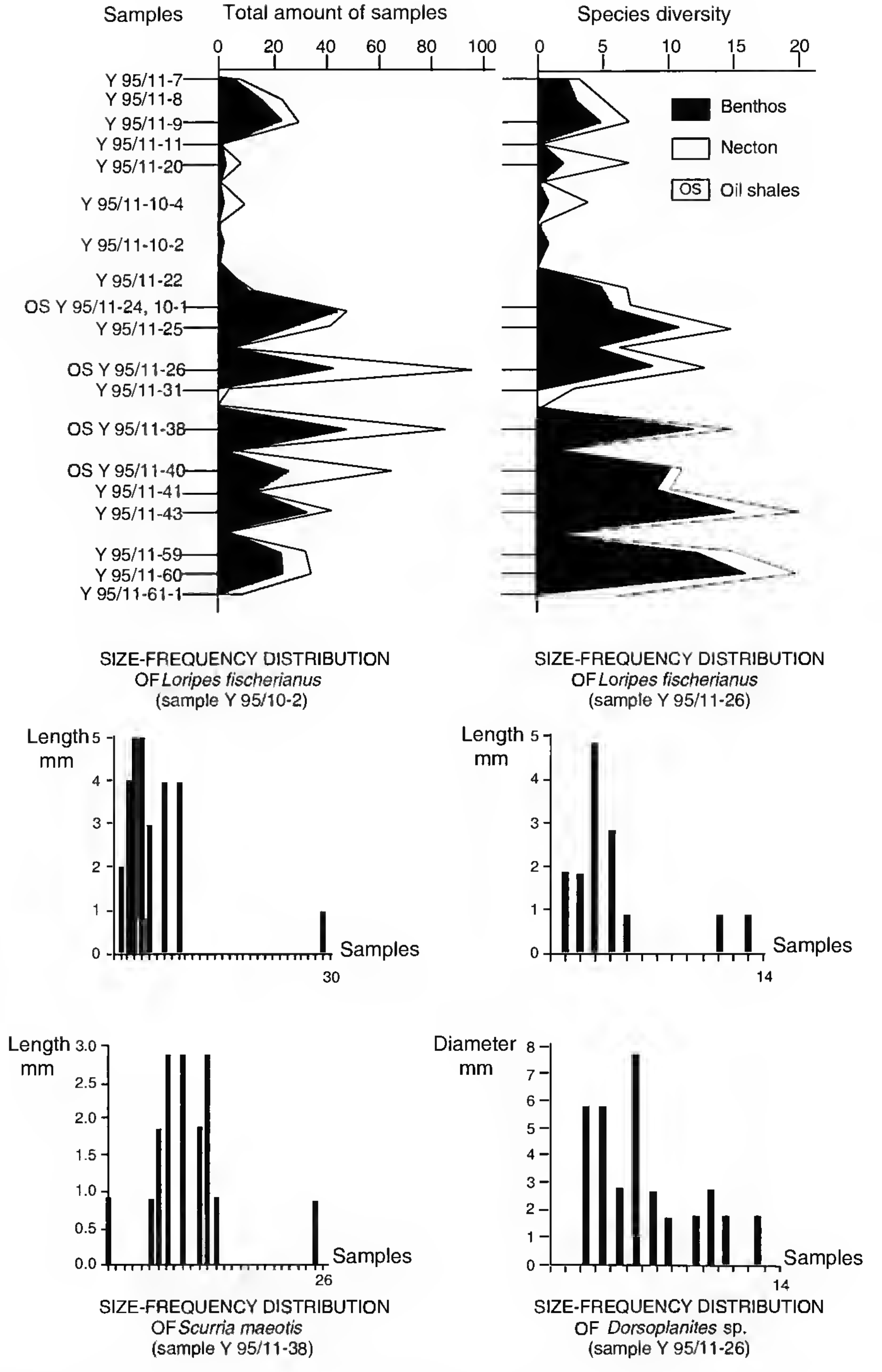

FIG. 4. — The distribution of sampling and percentages of macrofauna in the Gorodische Section.

The upper Kimmeridgian (*Eudoxus-Autissiodorensis* ammonite zones) sequences of the Gorodische Section are represented by clay marl with abundant nannofossils. *Tergestiella margereli, Watznaueria communis* and *W. britannica* are the dominant species. The characteristic species are *Stephanolithion bigoti, Discorhabdus tubus, Podorhabdus cylindratus, P. decussatus, P. cuvillieri,* as well as the smallest individuals of *Nannoconus steinmanni* (= *N. colomi*). This nannoplankton assemblage is similar to the NW European *Vekshinella stradneri* assemblage of Bernard & Hay (1974). A more precise Kimmeridgian radiolarian zonation may be developed in the near future.

The North Caucasus Kimmeridgian-Tithonian assemblages include only rare *P. dhimenaensis* (Baumgartner) and Berriassian assemblages include *P. boesii* (Parona) (Vishnevskaya *et al.* 1990). The content of parvicingulides is less than 5% of the total assemblage in the Tethyan Realm.

VOLGIAN BIOSTRATIGRAPHY OF THE PECHORA BASIN AND GORODISCHE STANDARD SECTION

Volgian strata have a transgressive character in the Pechora region (Fig. 5). Among radiolarians which occur within the middle Volgian *Dorsoplanites panderi* ammonite zone, *Parvicingula papulata* Kozlova, *P. conica* (Khabakov), *P. cristata* Kozlova, *P. rugosa* Kozlova, *P. simplicim* Kozlova are the dominant species. Parvicingulides again comprise up to 90% of faunas in the Barents-Pechora region. Ammonites, buchias and foraminifera are also abundant in these strata.

The Gorodische Standard Section is the section which has been most completely processed for macro- and microfauna (Figs 2-4).

Studies of the macrofaunal assemblage from the Gorodische Section show (cf. Mitta 1993), that strata in the section can be confidently assigned to two ammonite subzones of the (middle Volgian) *Dorsoplanites panderi* zone: The *Pavlovia pavlovi* bottom subzone and *Zaraiskites zarajskensis* top subzone, which were established by Gerasimov & Michailov (1966).

The *pavlovi* subzone (layers 61-59) is characterised by clayey-carbonate succession with thin phosphorite and marcasite horizons (Fig. 3). Several erosional surfaces are recognised in the subzone. Other ammonites include *Zaraiskites* sp., *Z.* cf. *tschernyschovi, Z.* cf. *michalskii, Dorsoplanites* aff. *panderi, D.* sp., *Pavlovia* sp., numerous rostrums of *Lagonibelus* (*L.*) *parvula* together with a benthic faunal assemblage of the bivalves *Loripes fischerianus, Buchia russiensis, Oxytoma* sp., *Protocardia concinna, Gresslya alduini,* gastropods *Eucyclus* sp., *Apporhais* sp., brachiopods *Lingula* sp., *Rusiella* sp., *Rhynchonella loxie*; scaphopods *Laevidentalium,* as well as serpulids. These assemblages permit us to characterise sedimentary conditions as weakly anoxic shallow water.

A somewhat richer fossil complex is present in the *zarajskensis* subzone (layers 58-23). The rocks of this subzone have rhythmical structure. Rhythms usually begin with horizons of reworked and dissolved fauna. They are overlain by carbonate clays topped with oil shale. The quantity of organic matter increases from 1-1.5% up to almost 22% at the background of decrease of carbonate matter (Fig. 3). Rhythmic changes in the benthic assemblage occur from a prevalence of benthos to an upsection increase of nekton (Fig. 4). In the oil shales young populations of lost *Loripes fischerianus* and *Scurria maeotis* usually prevail, together with nepionic ammonites. This demonstrates a strong anoxic impulse during the oil shale formation. The following faunal assemblage was determined from that interval: ammonites *Zaraiskites* cf. *scythicus, Z. pilicensis, Z. quenstedtii, Z. stchukinensis, Dorsoplanites panderi*; belemnites *Lagonibelus* (*L.*) *magnifica, L.* (*Holcobeloides*) *volgensis, L.* (*L.*) cf. *rosanovi*; bivalves *Astarte* sp., *Gresslya alduini, Buchia mosquensis, B. russiensis, Oxytoma* sp., *Loripes fischerianus, Nucula* sp., *Panopea* sp., *Limatula consobrina, Liostrea plastica*; gastropods *Scurria maeotis, Eucyclus* sp.; scaphopods *Laevidentalium* sp.; brachiopods *Lingula* sp., *Rhynchonella rouillieri* and other fauna.

The radiolarians *Orbiculiforma* ex gr. *mclaughlini* Pessagno, *Stichocapsa*? *devorata* (Rust), *Phormocampe favosa* Khudyaev, *Parvicingula hexagonata* (Heitzer), *P. cristata* Kozlova, *P. conica* (Khabakov), *P.* aff. *alata* Kozlova, *P. multipora*

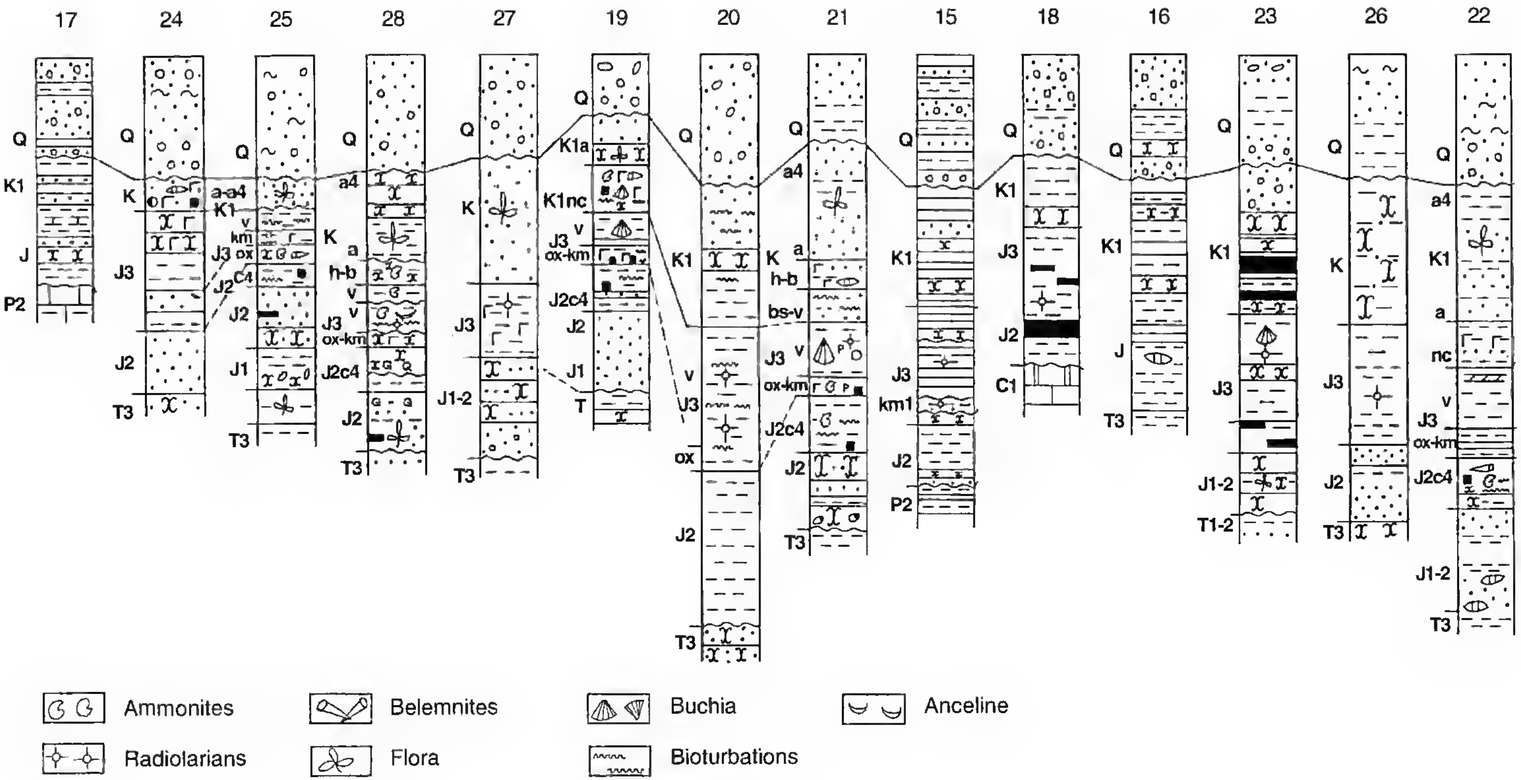

FIG. 5. — The distribution of Jurassic facies within the sections of the north-eastern part of the Russian Platform. For the location of boreholes see in Fig. 1. For legend of columns 1-14 see Vishnevskaya (1998), 29-52 see Vishnevskaya & Sedaeva (1999). **P**, Permian; **T**, Triassic; **J**, Jurassic; **K**, Cretaceous; **Q**, Tertiary; **a**, Aptian; **al**, Albian; **h-b**, Hauterivian-Barremian; **bs-v**, Berriassian-Valanginian; **nc**, Neocomian; **v**, Volgian; **ox-km**, Oxfordian-Kimmeridgian; **cl**, Callovian.

(Khudyaev), *P.* aff. *haeckeli* (Pantanelli), *P.* aff. *spinosa* (Grill & Kozur), *Plathycryphalus? pumilus* Rust, *Lithocampe* cf. *teruiseriata* Rust were recovered from within the *Dorsoplanites panderi* ammonite zone in the *Z. zarajskensis* subzone – the uppermost part of nannofossil *Watznaueria communis* zone of the Gorodische Section, where dominant species of coccoliths are *W. martelae*, *W. strigosa*, *W. tubulata*, *W. ovata*.

Higher in the section (layers 22-20) thin members of quartz-glauconitic sands and sandstones build up the succession. They contain horizons with reworked phosphorites. Faunas are located predominantly in rewashed pebbles. In layer 20, remains of strongly reworked zonal index *Virgatites gerassimovi* were found together with *Loripes* sp. and dissolved rostrums of *Lagonibelus* (*H.*) *volgensis*. There are many radiolarians reworked from the *Z. zarajskensis* subzone within the phosphorite pebbles.

Ammonites from the succeeding *Virgatites virgatus* next zone were not discovered. However, on the basis of stratigraphic position in a detailed section, this zone most likely occurs between layers 18 and 20.

The uppermost part of section is comprises dense thin members of carbonate sandstones with huge ammonites *Epivirgatites bipliciformis* and *E. nikitini* (layers 17-12) from the middle Volgian *E. nikitini* zone.

Sandstones of the upper Volgian *Kachpurites fulgens* zone lie above an erosional surface. They contain *Craspedites nekrassovi*, *C.* sp. and *Kachpurites fulgens* associated with *Buchia piochii*, *B.* sp., belemnites *Acroteuthis* (*A.*) *russiensis* and *A.* (*A.*) *mosquensis*, which were found in layers 11 and 10.

Overlapping layers 7, 8 also lie above erosional surfaces erosion and are characterised by reworked *Craspedites* cf. *okensis*, which is the diagnostic form of the upper Volgian *Craspedites subditus* zone. The belemnites *Acroteuthis* (*A.*) *mosquensis* and bivalve *Buchia piochii* and *B. tenuicollis* occur together with these ammonites. Radiolarian species *P. cristata* Kozlova, *P. alata* Kozlova, *P. blowi* (Pessagno) and *Stichocapsa devorata* (Rust) are common within these strata in which the parvicingulid content is 50-60%.

No ammonite fauna was found in layers 6-5 , but based on existing literature (Mesezhnikov 1984), these strata can be correlated with the upper Volgian *Craspedites nodiger* zone and lower Valanginian *Temnoptychites syzranicus* zone. The uppermost part of Volgian stage is characterised by appearance, within the radiolarian microfauna, of the Mediterranean species *P. boesii* (Parona).

The appearance of this Mediterranean species taxon notwithstanding, radiolarian assemblages are dominantly Boreal in character and the types of radiolarian assemblages present have not been described previously. The proposed middle Volgian *Parvicingula haeckeli* zone is closely correlated to the *Parvicingula papulata* zone of the Pechora Region (Kozlova 1994). It correlates with the ammonite *Dorsoplanites panderi* zone which can, in turn, be correlated with the *Evolutinella emeljanzevi-Trachammina septentrionalis* or *Saracenaria pravoslavlevi* foraminiferal zone (Kozlova 1994) in the Pechora Basin, *Lenticulina biexcavata* zone (Ljurov 1995) in the Sysola hydrocarbon Basin, and *Parhabdolithus embergeri* nannoplankton zone in Middle Volga hydrocarbon Basin. We can trace last zone through both Southern England and North France (Vishnevskaya & De Wever 1996). Due to the presence of index species, it is possible to correlate this interval with buchias *Buchia mosquensis-B. russiensis* zone of the Russian Platform (Sey & Kalacheva 1993).

The proposed upper Volgian *Parvicingula blowi* zone probably corresponds to the *Pseudocrolanium planocephala* assemblage of the Pechora and North Siberia regions which was established by Kozlova (1994) and can be correlated with *Buchia piochii-B. terebratuloides* zone of the Russian Platform (Sey & Kalacheva 1993).

JURASSIC PALAEOGEOGRAPHY

The Jurassic stratigraphic sequences in the Timan-Pechora Basin (Fig. 5) clearly show a transgressive depositional system starting with Early-Middle Jurassic sands and deepening upward to the accumulation of the higher grade source rocks in the Volgian time. The mass extinction, observed here and especially in the Gorodische Section of the Volga-Urals Basin

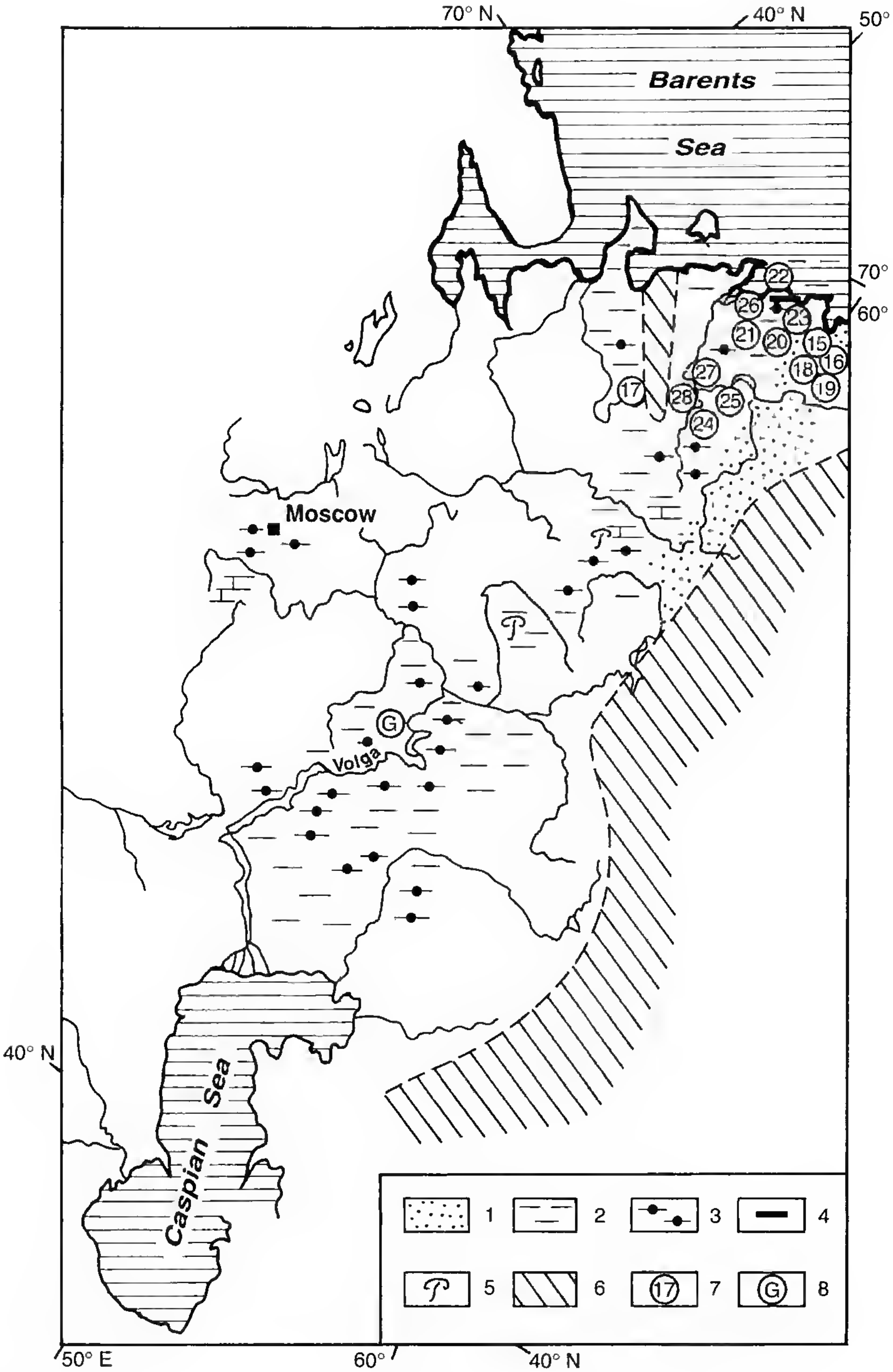

FIG. 6. — Schematic palaeofacies location map of the Kimmeridgian time (adopted after Sedaeva & Vishnevskaya 1995). **1**, coastal marine sandstone and siltstone; **2**, marine clay; **3**, anoxic organic shale; **4**, lignite coal and organic detritus; **5**, phosphate; **6**, supposed land; **7**, location of sections from Fig. 5 (number in circle); **8**, location of the Gorodische outcrops (letter in circle).

(only about 40 species of ammonites, 20 species of aucellids, 22 species of benthic foraminiferas and 20 species of planktonic foraminiferas, 10 species of belemnites, 5-40 calcareous nannofossil taxa, 20 species of radiolarians and several species of algae were recognised within *Dorsoplanites panderi* zone), probably resulted from the cumulative effects of a constant alternation of transgressive and regressive episodes. This type of sedimentation and palaeoenvironments survived into late Volgian time, but a change of conditions had already appeared by the end of Volgian time.

The proposed schematic palaeogeographic maps of the Kimmeridgian and Volgian time (Figs 7, 8) indicate the location of the eastern rim of shallow sea with excellent environments for oil and fuel-rich organic source rocks (Figs 5, 6). Similar to Recent seas and to an ancient sea, for example, the Devonian Sea (Vishnevskaya 1993), the maximum concentrations of phytoplankton, siliceous plankton and benthos, carbonaceous plankton, nekton and benthos were found in the water immediately bordering the continent. This type of relative increase in the proportion of lipid rich organic matter in the bottom sediments and its good preservation probably took place in response to the preservative character of phosphorus, the content of which is very high in these strata (Baudin *et al.* 1996).

It is well-known that in the Tethyan Realm the genus *Parvicingula* is rare whereas the content of this genus in the Boreal (Khydjaev 1931; Sedaeva & Vishnevskaya 1995) and Australian provinces (Baumgartner 1993) is much greater. From these data, we can assume that cold water environments dominated the north-eastern Russian Platform Jurassic oil-shale-bearing basin. The preponderance of parvicingulides possibly indicates upwelling conditions which have could existed offshore (Figs 6-8). The abundant remains of sponge spicules, which settled along the shelf edge confirm this conclusion.

JURASSIC BIOSTRATIGRAPHY AND PALAEOGEOGRAPHY

Detailed analysis of taxonomic variety of faunal assemblages and some morphological peculiarities of shells allow us to establish biostratigraphic correlations and to reconstruct the possible bathymetric and topographic features of sedimentary basins. One would notice that Jurassic radiolarian fauna was firstly found from the Gorodische Standard Section of the Volga Basin. It represents new data on the palaeontological characteristics of the Upper Jurassic Russian Regional Volgian Stage. The lower Kimmeridgian ammonite *Amoeboceras kitchini* (Salfeld) is typical of the Arctic (Northern Siberia, Subpolar Urals) and Boreal-Atlantic Provinces (European Russia). *Buchia* is a characteristic element of Arctic and Boreal realms. Foraminiferas are also typical of the Boreal-Atlantic Province. A typical feature of radiolarian assemblages (abundance and high taxonomic diversity of the genus *Parvicingula*) indicates Boreal affinity. The presence of the genus *Aspidoceras* in the Volga-Oka Basin, well-known in the Western Europe and Mediterranean Region, is the only indicator of possible Tethyan influence.

Some peculiarities were common for sediments of the Pechora and Volga basins:

1. Sedimentary lithologies and their thicknesses indicate uneven subsidence on the periphery of Russian Platform.
2. Alternation of deep-water and shallow-water sediments and numerous gaps indicate eustatic variations.
3. Geochemical data exhibit enrichment in organic matter.

New siliceous microfossil radiolarian assemblages have been obtained from the Volgian as dated by ammonites and calcareous nannofossils.

The co-occurrence of radiolarians with calcareous nannofossils represents the first well-dated radiolarian assemblage of this age at such a high latitude on the Russian Platform.

As might be expected many new radiolarian species of the Boreal Province are encountered.

LOWER CRETACEOUS STRATIGRAPHY OF ULJANOVSK-PENZA REGION

Berriasian strata are probably reworked in the Gorodische Section, although they were marked

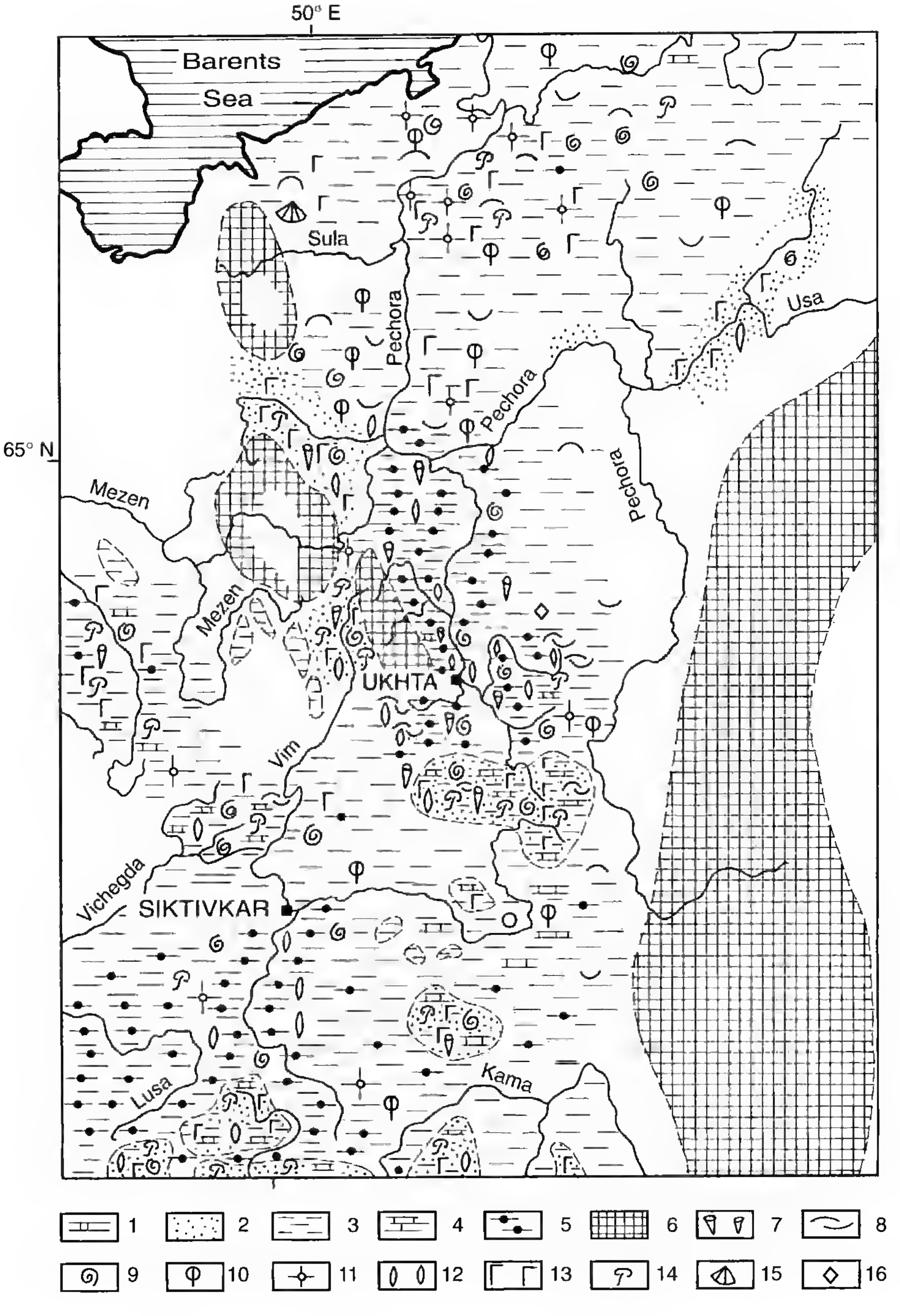

FIG. 7. — A detail palaeogeographic map of the Volgian time. **1**, marl; **2**, sand; **3**, clay; **4**, limestone; **5**, oil shale; **6**, land; **7**, sponge; **8**, aucelline; **9**, ammonite; **10**, foraminifera; **11**, radiolaria; **12**, bivalve; **13**, glauconite; **14**, phosphate; **15**, buchia; **16**, gypsum.

(?mapped) according to Mesezhnikov (1984). From our point of view, the presence of Berriasian deposits here is improbable because the section is strongly condensed. Most probably, Berriasian ammonites which are present in these strata were reworked into the base of Valanginian.

The section is terminated by black clays (layers 4-1) with siderite and limonite concretions, containing large weathered ammonites *Speetoniceras (S.) versicolor* and *S. (S.) subinversum*, which are ascribed to the *Speetoniceras inversum* zone of the top Hauterivian.

An anoxic event occurred within the lower Aptian *Deshayesites deshayesi* zone. The remainder of the lower and middle Aptian is characterised by anaerobic conditions. A late Albian radiolarian assemblage was found amongst the Albian black clay of Uljanovsk Section. It is represented by *Orbiculiforma multangula* Pessagno, *Theocampe cylindrica* Smirnova & Aliev, *Obeliscoites turris* (Squinabol).

The Barremian-Albian intervals were also investigated in two (7, 10) boreholes in the Penza area. At a depth of 89 m in borehole 10, the radiolarians *Orbiculiforma maxima* Pessagno, *Distylocapsa micropora* (Squinabol), similar to late Albian Tethyan forms (O' Dogherty 1995); *Dictyomitra communis* (Squinabol) and *Obesacapsula* sp. cf. *O. zamorensis* Pessagno were recovered. At a depth of 105.5 m in the same borehole, typical late Albian radiolarian species *Porodiscus kavilkinensis* Aliev, *Archaeodictyomitra simplex* Pessagno, *Dictyomitra gracilis* (Squinabol), *Dictyomitra ferosia angusta* Smirnova, *Theocampe cylindrica* Smirnova & Aliev were recognised. At a depth of 106.8 m within borehole 10, the radiolarian fauna is characterised by Spumellaria only.

Within borehole 7, at a depth of 113.3 m, radiolarians *Orbiculiforma nevadaensis* Pessagno, *Obeliscoites perspicuus* Squinabol, *O.* cf. *vinassai* (Squinabol), *Xitus antelopensis* Pessagno, *X.? asymbator* Foreman, which are characteristic species of the Albian to early Cenomanian, were found. At a depth of 120 m (borehole 7) radiolarians are represented by the species *Orbiculiforma nevadaensis* Pessagno and typical late Albian *Theocampe cylindrica* Smirnova & Aliev, *T. simplex* Smirnova & Aliev.

Between 123.45 and 123.50 m, the radiolarians *Porodiscus inflatus* Smirnova & Aliev, *Obeliscoites turris* (Squinabol) are present.

At a depth of 133.15 to 133.25 m the radiolarians *Dictyomitra ferosia angusta* Smirnova and *Stichomitra communis* Squinabol were recovered. Within the interval 129.75 to 129.90 m, Albian species *Crolanium cuneatum* (Smirnova & Aliev), *C. triquetrum* Pessagno, *Porodiscus inflatus* Smirnova & Aliev were met.

At a depth of 136 m, the only species recovered was *Orbiculiforma multangula* Pessagno occurred. From the above data we consider that the Aptian-Albian *Crolanium cuneatum* zone can be recognised in the Uljanovsk-Penza Region.

UPPER CRETACEOUS BIOSTRATIGRAPHY OF VOLGA BASIN

Upper Cretaceous radiolarians were studied from the Shilovka Section in the Uljanovsk Region and from core sections of boreholes (28, 502) from the Volgograd Region. Three radiolarian assemblages were determined: *Archaeospongoprunum bipartitum-Alievium superbum* (Turonian-Coniacian), *Pseudoaulophacus floresensis-Euchitonia santonica* (late Coniacian-Santonian or Santonian) and *Amphipyndax tylotus-Patellula planoconvexa* (late Campanian). Age data were supported by foraminiferal and nannoplankton assemblages, which have affinity with European ones. These assemblages are similar to Western Siberian Boreal associations, but include some Tethyan taxa.

The early Santonian *Euchitonia santonica-Alievium praegallowayi* zone was established by Vishnevskaya (1997). It is a characteristic Boreal zone and is widespread both in Siberian, Russian platforms and in the Pre-Caucasus. Within the Shilovka Section, it corresponds to the foraminiferal *Gavelinella infrasantonica* zone or nannoplankton *Marthasterites furcatus* zone. The late Santonian-early Campanian foraminiferal *Gavelinella stelligera* zone can be correlated with the *Orbiculiforma quadrata-Lithostrobus rostovzevi* zone. The upper part of this zone may be calibrated with the nannoplankton *Arkhangelskiella specillata* zone in the Shilovka and Tushna sec-

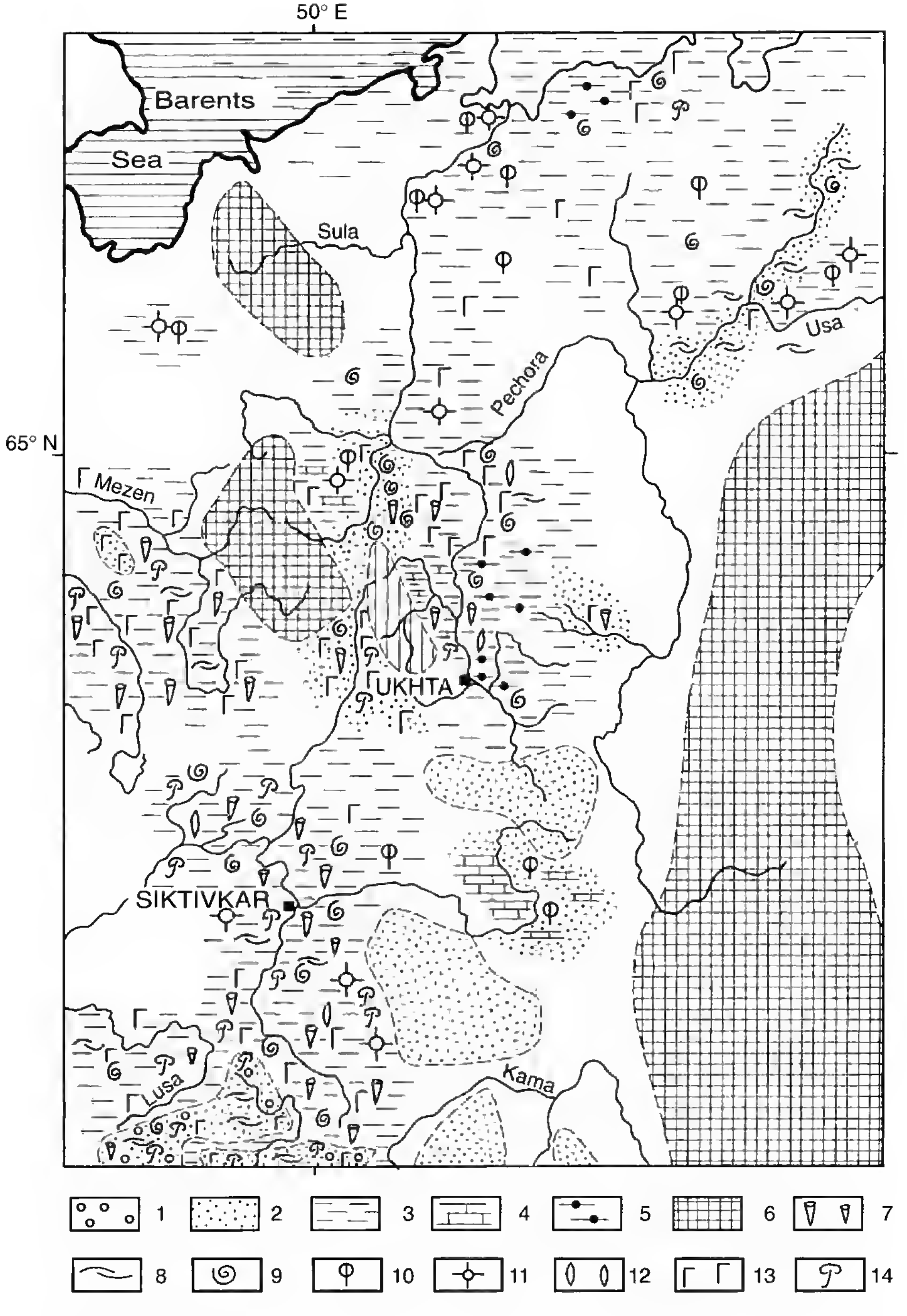

FIG. 8. —A detail palaeogeographical map of Kimmeridgian time. Legend: see on Fig. 7, only **1**, gravellite.

tions. Campanian *Prunobrachium articulatum* zone (Lipman 1952) or *Amphibrachium sibericum* zone and *Spongoprunum angustum* zones (Amon & De Wever 1994) have no analogues in the Tethyan Region. Nevertheless, the Tethyan species *Afens liriodes* Riedel & Sanfilippo was found in the interval of this zone within the Shilovka Section.

CONCLUSION

The proposed biostratigraphic subdivisions based on new palaeontological data are clearly definable. They have a proven wide geographic distribution and can be useful for correlation of sedimentary sequences as well as biotic and abiotic events.

The direct correlation of Peri-Tethyan radiolarian zonations with oceanic ones and those of the Tethyan region is very difficult owing to provinciality of species. Only one Jurassic zone, the upper Volgian-lower Berriasian *Parvicingula blowi* zone, can probably be compared with zonations of Baumgartner (1993) for the Argo Basin. The upper Berriasian-lower Valanginian *Parvicingula khabakovi-Williriedellum salumicum* zone (Vishnevskaya 1996), which is widespread in the Russian and Siberian platforms within the ammonite *Bojarkia mesezhnikovi* zone, can be compare with some Tethyan ones owing to the presence of numerous *Parvicingula boesii*.

Biostratigraphic correlations of microfossils (radiolarians, foraminiferas and nannoplankton) and macrofossils (ammonites, buchias) is proposed in order to establish the synchronicity of events and consequently of more general geological processes.

Acknowledgements

We express our gratitude to Professor A. Nikishin and anonymous reviewers for their stimulating comments and criticism on the paper. We are grateful to J. Aitchison who helped us to improve the English. Special thanks are due to Peri-Tethys Programme (grants 9518 and 95-96/18) and Russian Foundation for Basic Research for financial support (Grant RFFI 97-05-65566) and to CNRS-ESA 7073.

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Some features of the Early Cretaceous sedimentation in the Cis-Caucasia reflected in magnetic properties of the sedimentary cover

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ABSTRACT
This paper present the results from petromagnetic studies of the North Caucasus-Lower Cretaceous deposits. Analyses of the magnetic properties of rocks in base sections have allowed to reveal several impulses of tectonic activation in the Hauterivian and Barremian. The impulses were accompanied by transport of magnetic terrigenous material from the magnetic complexes of the Central Ridge into the Cis-Caucasian Basin.

KEY WORDS
Petromagnetism,
scalar magnetic characteristics,
magnetic susceptibility,
Para-Tethys,
Early Cretaceous.

RÉSUMÉ
Quelques caractéristiques de la sédimentation du Crétacé inférieur en Cis-Caucasie à travers les propriétés pétromagnétiques de la couverture sédimentaire.
Cet article présente les résultats d'une étude pétromagnétique sur les dépôts du Crétacé inférieur du Nord Caucase. Les analyses des propriétés magnétiques des roches ont montré plusieurs poussées de l'activité tectonique durant l'Hauterivien et le Barrémien. Ces impulsions se sont accompagnées d'un transport du matériel terrigène depuis les complexes magnétiques de la ride centrale jusque dans le bassin Cis-Ouralien.

MOTS CLÉS
Pétromagnétisme,
caractéristiques magnétiques,
susceptibilité magnétique,
Para-Téthys,
Crétacé inférieur.

INTRODUCTION

The results of petromagnetic research on the Lower Cretaceous deposits from the central and eastern parts of the North Caucasus are presented with the geologic interprerations. Six reference sections from Dagestan, Chechnya, Kabarda and the Mineral Water District were examined (Fig. 1). They contain carbonate and terrigenous facies of the marine Lower Cretaceous (Berriasian to Albian).

The geologic history of the region is considered in voluminous literature, with the early stage of its development being analysed both from the positions of classical fixism, and on the basis of more recent mobilisric ideas.

The fixist conception states that the Caucasus was developing according to the classic geosyncline scheme, with the principal structural elements inherited from the end of the Palaeozoic-beginning of the Mesozoic (Shevchenko & Rezanov 1978; Sholpo 1978). The mobilistic models present the geodynamic evolution of the Caucasian region as resulting from continental plates crushing and moving apart, and the Benioff zones rifting and subsequently migrating southwards (Khain 1975; Adamiya *et al.* 1982).

The analyses of the lithofacies spatial divisions and thickness of the Lower Cretaceous rocks, have revealed the principal structures forming the frame of the North Caucasian Region (Sholpo 1978): (1) the elevated southern margin of the Scythian Plate, conjugated with the transversal Stavropol high; (2) an intensive submergence zone, spatially concurrent with the Terek-Caspian piedmont trough; (3) the elevation of the Great Caucasus (Fig. 1).

The nature of these structures is interpreted in different ways. Some authors regard the zone of the Great Caucasus as an inherited horst-anticlinorium Mesozoic (Shevchenko & Rezanov 1978; Sholpo 1978), others – as an island arc (Khain 1975; Adamiya *et al.* 1982). The Terek-Caspian trough is accordingly interpreted as a geosyncline axial zone or a marginal island-arc basin.

For our reconstructions, it is important to note, that irrespective of palaeotectonic interpretations, two geomorphologically distinct sourcelands, the northern and the southern ones exist in the Early Cretaceous, with an intermediate zone of intensive submergence; this latter one acting as an area of active marine sedimentation in the Early Cretaceous. The Mesozoic palaeogeography of the North Caucasus is generally being analysed at the level of major sedimentation-tectonic cycles, frequently uniting several geologic periods and epochs (Khain 1968; Dorduev 1989). Konyukhov & Olenin (1955) and Konyukhov (1961) recognised an independent Lower Cretaceous Stage in the geologic development of the eastern Cis-Caucasia; this is peculiar for a prolonged transgression, that has started in the Berriasian and continued through the Late Albian. Carbonate-terrigenous sedimentation prevailed during the early stage of the Lower Cretaceous transgression (Berriasian-Valanginian). Terrigenous deposits are characteristic of the Barremian, Aptian and Albian.

The determination of the terrigenous inflow sources to the Cis-Caucasian Basin presents one of the debatable problems for the Mesozoic palaeogeography of the North Caucasus. This problem is discussed in detail in a number of important papers on the lithology of the Mesozoic sedimentary complexes from the region, but the authors have different conclusions. Konyukhov (1961) considered the Northern Land to have been the principal distributive province during the whole of the Lower Cretaceous. Grossgeim (1961) cited the elevations of the Great Caucasus as the main distributive province. Expanding Grossgeim's scheme (1961), Sholpo (1978) supposes, that in the Callovian, the Caucasus has undergone active erosion, that has practically stopped in the Neocomian, resumed in the late Barremian and reached its maximum in the Aptian and Albian.

In this paper, the authors got some additional palaeogeographic information while analysing the data on scalar magnetic characteristics of the Lower Cretaceous beds from the North Caucasus. The petromagnetic data let us to carry out the detailed analyses of sedimentation in the Early Cretaceous, to specify the importance of the northern and southern distributive provinces and to evaluate the changes of the palaeogeochemical conditions in the course of transgression development.

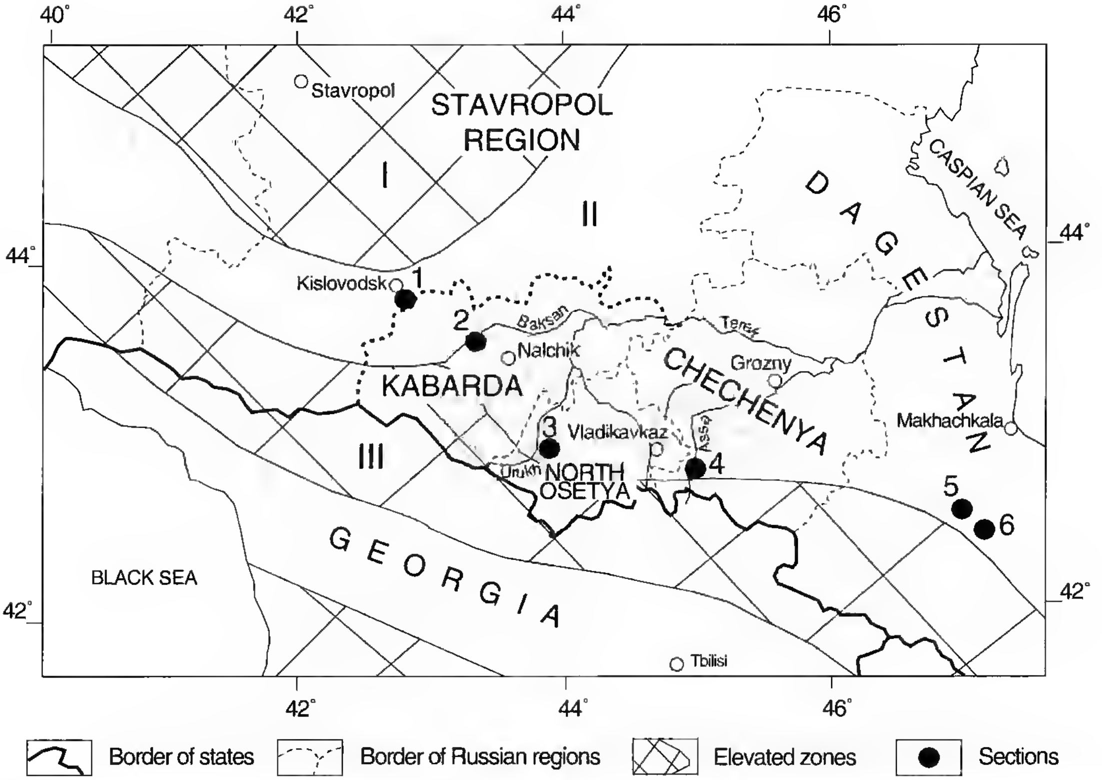

FIG. 1. — Location map. Sections: **1**, Kislovodsk city; **2**, the Baksan River; **3**, the Urukh River; **4**, the Assa River; **5**, Gergebil Village; **6**, Akusha Village. **I**, the southern margin of the Scythian Plate (Stavropol High); **II**, the Terek-Caspian piedmont trough; **III**, elevation of the Great Caucasus.

RESULTS

Magnetic measurements of the rocks from 1500 stratigraphic levels were performed in six Lower Cretaceous reference sections (Fig. 1). Petromagnetic sampling from two sections (Kislovodsk and Gergebil) was duplicated in the adjacent outcrops of the same age. Various facies were examined: limestones, marls, sandstones, aleurolites and clays. A significant spectrum of magnetic features was analysed in the course of laboratory experiments: magnetic susceptibility (k), natural remanent magnetisation (Jn), remanent saturation magnetisation (Jrs), destructive field of remanent saturation magnetisation (H'cs), and magnetic susceptibility measured upon heating the rocks up to 500° in air medium (k_t). The variations in the $dk = k_t - k$ parameter reflect the concentration changes of initially nonmagnetic iron sulphides. Pyrite and marcasite change into magnetite upon heating, which results in increasing magnetic susceptibility. Thus, dk increase reflects the contents of newly generated magnetite, and consequently, the concentrations of original FeS_2.

The data summarised have shown many magnetic characteristics to render generally similar information. To avoid the unnecessary duplication, only the k and dk parameters are used in the present paper.

Optical methods and thermodifferential analyses have demonstrated detrital magnetite to be the principal magnetic medium in the bulk of samples. Its presence is diagnosed in thermomagnetic curves from disappearance of remanent magnetisation around 580 °C (magnetite Curie point) (Fig. 2A-C). Magnetic saturations of the samples have revealed the magnetically mild

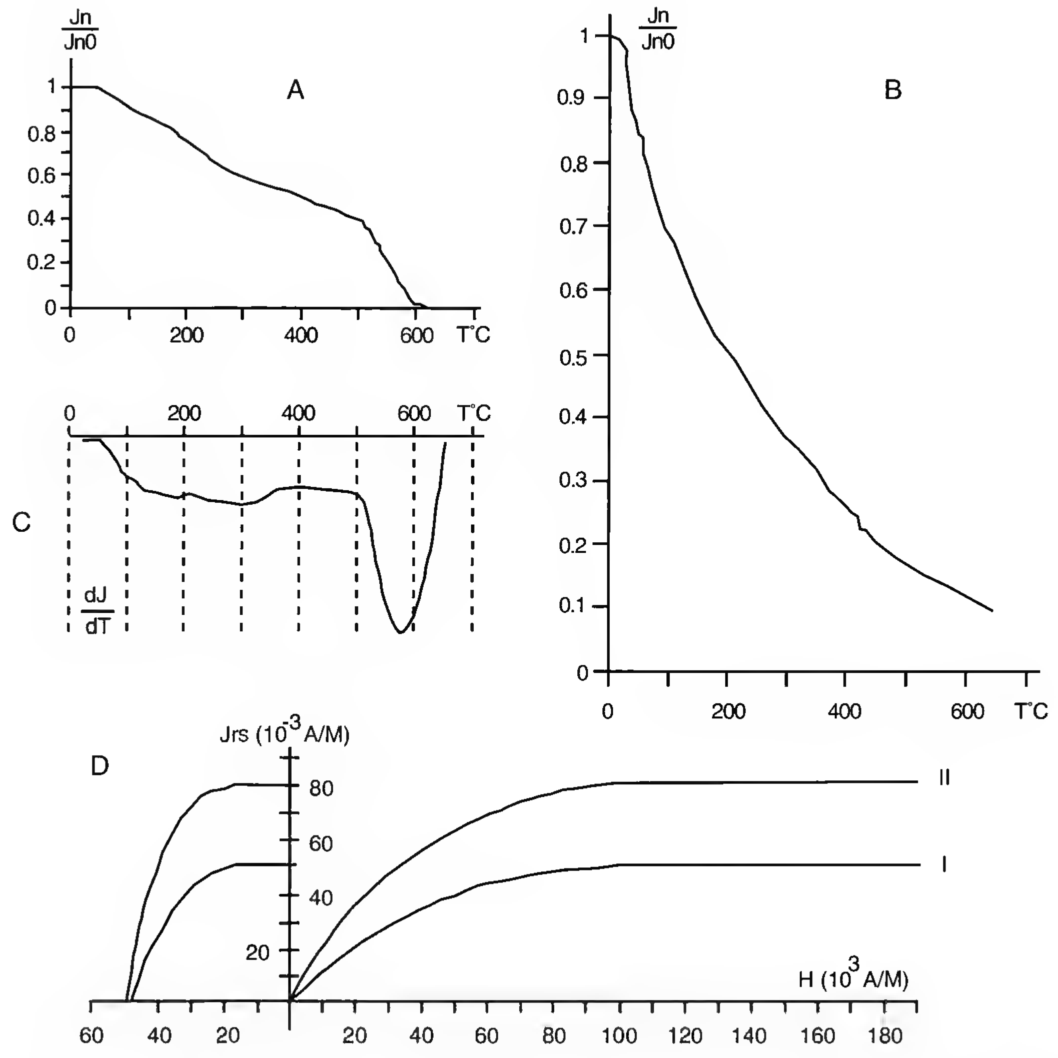

FIG. 2. — Results of magneto-mineralogic analyses for the Lower Cretaceous deposits from the North Caucasus. Thermodemagnetisation curves: **A**, clay (Aptian, Gergebil Village); **B**, limestone (Hauterivian, Gergebil Village); **C**, differential thermomagnetic analysis curve for aleurolite (Hauterivian, the Baksan River); **D**, magnetic saturation and demagnetisation curves: **I**, for aleurolite (Berriasian, the Assa River); **II**, for sandstone (Barremian, Akusha Village).

phase Hs = 32-64 A/m, H'cs = 24-50 magnetite (Fig. 2D). The data of immersional analyses testify to allothigenic nature of magnetite. The coarsest Fe_3O_4 grains are angular and possess clear traces of transportation by water: scratches and hatching on the sides and edges.

Grossgeim's data (1961) confirm the conclusion, that magnetic features of the Lower Cretaceous beds from the Cis-Caucasia were controlled mainly by detrital magnetism.

Carbonate beds are peculiar for extremely low magnetism. Terrigenous complex is characterised by considerable variations in magnetic susceptibilities. Their levels are practically independent on rock lithologies or structural-textural features, but are generally determined by the spatial-structural positions of the sections and by the stratigraphic positions of the sequences.

According to its petromagnetic properties, the Lower Cretaceous terrigenous complex from the

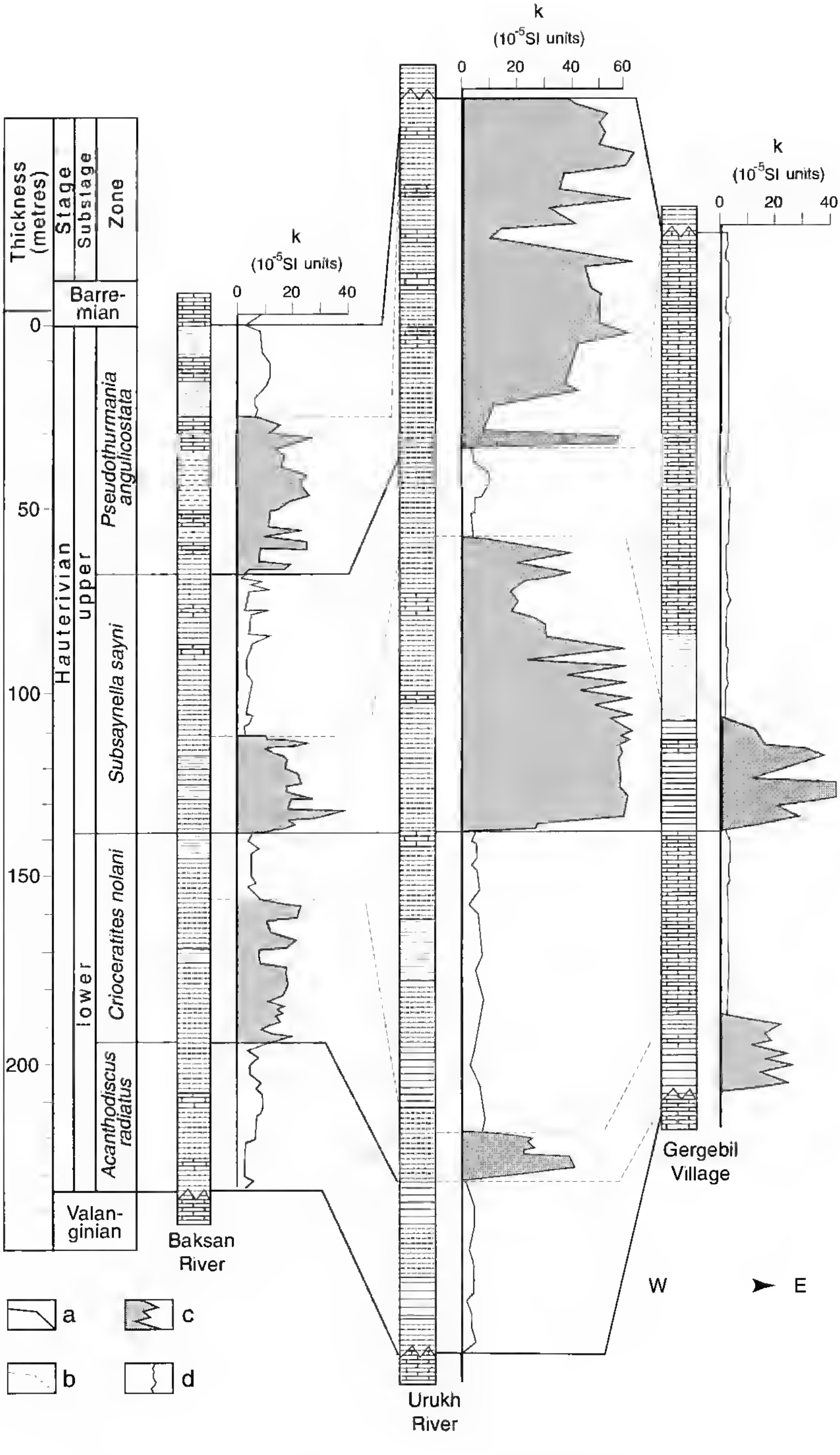

FIG. 3. — Palaeontologic and petromagnetic correlations of the Hauterivian deposits from the North Caucasus. a, correlation lines according to palaeontological data; **b**, *idem* according to petromagnetic data; **c**, petromagnetic intervals highly magnetic; **d**, *idem* low magnetic. For legend of lithology and gap, see Appendix 1.

North Caucasus may be divided into two distinct parts (Appendixes 1-6) in all the sections, except the Kislovodsk one (Appendix 1). The Hauterivian-Barremian beds stand out against the general background due to higher magnetism and great dispersion of magnetic values. Alternating groups of highly and low magnetic layers are recognised within the sections, with the thickness of 10 to 100 m and the magnitudes of Jn and k varying between 1-65.10^{-5} SI units and 0.2-3.10^{-3} A/m, respectively.

A certain sequence may be outlined in distribution of the petromagnetic intervals over the stratigraphic section; the highly magnetic intervals correspond to the lower parts of biozones or substages, and the low magnetic ones-to the upper parts. Thus, all the Hauterivian biozones (except the *Acanthodiscus radiatus* one) and Barremian substages correspond to binomial petromagnetic rhythms (PR), with the boundaries defined from sharp (by the factors of two, three or more) differences in Jn and k values (Appendixes 1-6).

The number of rhythms and the thickness are not constant and depend on the section completeness and sedimentation rates in various structural-facies zones. On the basis of all the considered data, at least three petromagnetic rhythms are recognised in the Hauterivian (Fig. 3). All of them occupy some definite stratigraphic positions and may be used for detailed section divisions and correlations, evaluation of washouts and sedimentation gaps (Fig. 3).

Another peculiarity of the Hauterivian-Barremian sedimentation consists in distinct structural-spatial differentiation of the sediments according to their magnetic properties.

The littoral-marine sandstones from the Hauterivian Stage of the Mineral Water Region, are characterised by low and uniform magnetism (k = 0-3.10^{-5} SI units). The Hauterivian bed magnetism increases up to 10-20.10^{-5} SI units to the south-east, in the Baksan Section. The values reach their maxima in the Urukh River Basin, where most of the samples having k varying between 15-50.10^{-5} SI units over the whole of the Hauterivian and Barremian sections. In south-eastern Dagestan, the highly magnetic horizons are separated and localised in fairly narrow intervals of the section (Fig. 4).

The Cis-Caucasian Aptian and Albian beds form an independent lithological-magnetic complex, sharply different from the Hauterivian-Barremian one by its low magnerism (Fig. 4). In the Aptian deposits, the k values vary within 1-12.10^{-5} SI units without any significant differentiation over the section.

The Albian deposits are even lower magnetic (k = 1-10.10^{-5} SI units). Nevertheless, in Dagestan sections, four binomial petromagnetic rhythms may be outlined from variations in magnetic susceptibility. In the reference section of the Albian near the Akusha Village, the first thythm (K 1) covers the lower and the middle substages, the K 2 – the *Dipoloceras cristatum-Hysteroceras varicosum* zones, the K 3 – the *Mortoniceras inflatum* zone, and the K 4 – the *Stoliczkaia dispar* zone (appendix 6). In the lower rhythm, the boundary between the low and moderately magnetic intervals coincides with the *O. ryssianum/A. intermedius* biozone boundary.

A peculiar feature of the Aptian-Albian petromagnetic complex consists in a sharp increase of the rock magnetic susceptibilities in certain stratigraphic intervals, upon heating up to 500°.

The Lower Aptian and lowermost Middle Aptian (the *Epicheloniceras subnodosocostatum* zone) beds do not reveal any significant increase in magnetic susceptibility (Fig. 4).

An anomalous burst of dk values (up to 450.10^{-5} SI units) is associated in all the sections with the boundary between the Middle Aptian zones *E. subnodosocostatum* and *Parahoplites melchioris* (Fig. 4).

The thermokappametric diagrams for the deposits from the *P. melchioris* zone, Upper Aptian and Albian, have individual peculiarities in each of the sections (Fig. 4).

In the vicinity of Kislovodsk, high dk values (up to 400.10^{-5} SI units) are recorded only in the lower part of the *P. melchioris* zone.

In the basin of the Urukh, high values of magnetic susceptibility are characteristic both, of the Upper Aptian and of the Albian complexes (dk = 150-450.10^{-5} SI units and dk = 100-400.10^{-5} SI units, respectively).

In Dagestan, anormal dk values are characteristic of the uppermost Aptian and of the Albian. However, in the section near Gergebil, the

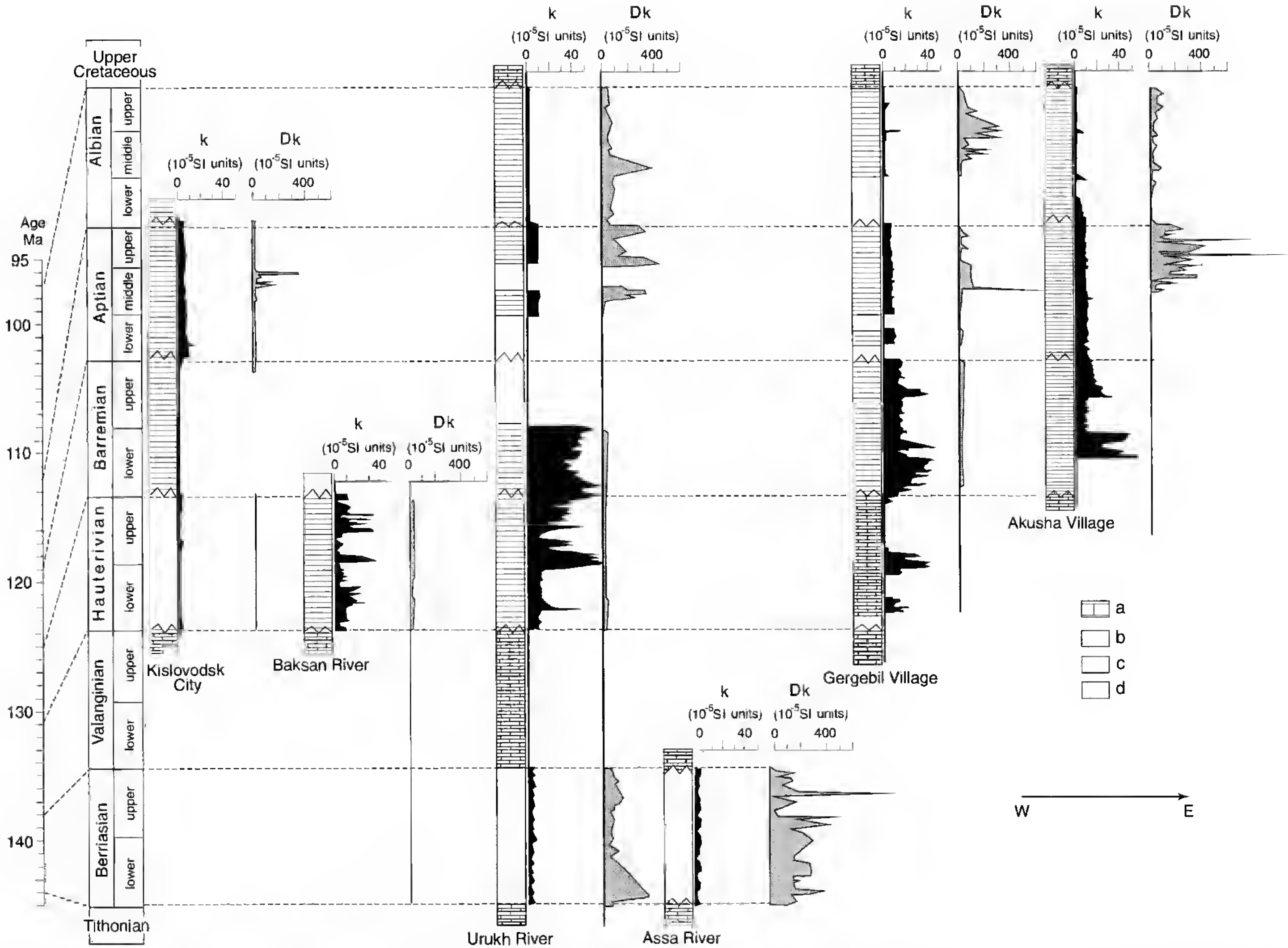

FIG. 4. — Petromagnetic characteristics of the Lower Cretaceous deposits from the North Caucasus (Age Ma from Harland *et al.* 1982). **a**, chiefly carbonate beds; **b**, chiefly terrigenous beds; **c**, carbonate-terrigenous beds; **d**, absence of deposits.

Albian is marked with highet dk values (to 300.10^{-5} SI units), than the upper Aptian, while the reverse is observed near Akusha.

Variations in magnetic susceptibility increase are associated with the palaeontological boundaries. Thus, in the Albian Section from Akusha, the smoothed dk curve (the dk curve was smoothed by means of calculating the sliding arithmetic mean from five samples, at a step of one sample, Appendix 6) demonstrated distinct rhythms, while three of its intervals with the dk > dkav stratigraphically coincide with the zones *Pseudosonneratia eodentata-Oxytropidoceras royssianum*, *H. orbignyi-H. varicosum* and *Stoliczkaia dispar*, respectively.

As seen in Figure 4, the values of k and dk parameters reveal clear inverse telationship: the highly magnetic Hauterivian-Barremian parts of the sections are characterized by minimal increases of magnetic susceptibility; on the contrary, the highest dk values are recorded in the low magnetic Aptian-Albian sequences.

PALAEOGEOGRAPHIC INTERPRETATION OF THE DATA

Rock magnetic properties are primarily determined by the compositions and concenttations of allothigenic or/and authigenic ferromagnetic minerals; these vary depending on sedimentation settings. From this follow the previously formulated postulates for the geologic interpretation of petromagnetic data (Molostovsky 1986; Guzhikov & Molostovsky 1995).

The following theses are relevant to the present theme:

1. The magnetisation intensity of sedimentary rocks, containing allothigenic ferromagnetics, is determined by the palaeogeographic and tectonic factors, controlling baring, drifting and precipitation of terrigenous materials. Petromagnetic differentiation of the layers in a stratigraphic section teflects deposition rhythms and changing sedimentation settings, resulting from geodynamic reconstructions in bating areas, and, mostly, from the sourceland changes.

2. Variations in the dk parameter adequately reflect changing geochemical settings and hydrogen-sulphide contamination of the bottom silts or its absence.

Complex analyses of the magnetic properties, and of the materials on lithofacies stratigraphic distributions on fossil biocoenoses, textural-sttuctural features of the rocks, allow to obtain a fairly complete idea of the evolution of sedimentation settings in the Cis-Caucasian Basin during the Early Cretaceous.

All the data combined, provide the grounds for recognising the independent Lower Cretaceous step in the geologic development of the North Caucasian Region, comprising seveial major stages, each one from 10.5 to 27.5 million years long.

The first stage, equivalent to the Berriasian and Valanginian, coincides with the beginning of a major transgression, marked by chiefly carbonate sedimentation. Deposition took place in the settings of a relatively shallow and well-oxygenated warm basin (Konyukhov & Olenin 1955; Konyukhov 1961; Khain 1968). The limited terrigenous input and extremely low magnetism of the rocks testify to the lowland terrain in probable sourcelands, and low magnetism of the source rocks.

The Hauterivian has opened a new stage in the Early Cretaceous sedimentation cycle. The consistent sea transgtession northwards, coincided with tectonic activation of the Great Caucasus and elevation of the southern margin of the Scythian Plate.

The increased magnetism of the Hauterivian-Barremian part of the section, indicates, that the principal sourceland did not lie in the Northern Land with the low magnetic sedimentary cover being washed out, but was situated in the Great Caucasus territory, characterised by wide development of the Upper Palaeozoic and Jurassic intrusions and of the dike complex of basites (Afanasyev 1968).

Judging from the characters of petromagnetic sections, the territory of the Central Caucasus was the principal magnetic material supplier to the Lower Cretaceous basin. The bulk of the magnetic terrigenous input was accumulated within the Osetin syncline, in the basins of the Baksan and Urukh. The eastern part of the Great

Caucasus was less important in this respect. The Western Caucasus, with its granitoid intrusions of Malkinskaya group, did not exert any obvious influence on the sedimentation in the Cis-Caucasian Basin. The southern part of the Scythian Plate and the adjacent Stavropol projection (Fig. 1) served as the main distributive provinces for the western part of the Central Cis-Caucasia. This is indicated by low and uniform magnetisation of the Hauterivian arkoses from the Mineral Water District (Fig. 4), practically devoid of ferromagnetic materials.

The petromagnetic differentiation of the sediments over the stratigraphic section, being adequate to sedimentation rhythms, testifies to pulsatory character of deposition and occasional changes of sourcelands. Chronologic coincidences of the petromagnetic rhythms and biozones are indicative of the event nature of magnetic and palaeontologic boundaries, and of their paragenetic dependence on the regional geodynamic events. This inference is consistent with the idea of the functional dependence of many biocoenotic shifts upon changing sedimentation settings (Zhizhhcenko 1969; Zubakov 1990).

Stabilising tectonic settings in the region of the Great Caucasus at the beginning of the Aptian, have led to rapid decrease in ferromagnetic input to the Cis-Caucasian Basin and, consequently, to sharp magnetisation decrease in bottom sediments. Starting from the Aptian, the Southern Land was no longer important as a sourceland. Thus, during the last stage of the Aptian-Albian sedimentation, the Northern Land, structurally linked to the margin of the Scythian Plate, becomes the principal distributive province.

The Aptian sequence is practically not differentiated according to scalar magnetic characteristics, which, under certain assumptions, may be interpreted as indicative of relatively stable tectonic settings. Judging from insignificant magnetism variations in the Albian sections, some activation has probably taken place in the end of the Early Cretaceous (Appendixes 5, 6, Fig. 4).

The regional redox potential reduction of deposition environment, constitutes a distinctive feature of the Aptian-Albian sedimentation within the North Caucasus. Anormally high concentrations of disseminated pyrite, reliably recorded from sharp k_t increases, are observed in all the sections studied, and testify to periodical contaminations of the bottom sediments in the Cis-Caucasia with hydrogen sulfide in the end of the Aptian (*P. melchioris* zone and the upper substage) and the Albian.

The magnitudes and durations of these process manifestations varied within wide ranges. Various intensities of dk in distant sections of the same ages (Fig. 4) are indicative of the changes in redox settings to have been peculiar in each of the facies zone (Fig. 4). In the Mineral Water District, the hydrogen-sulphide environment existed till the middle of the *P. melchioris* time. Within the Osetin syncline (the Urukh River) and Dagestan, it persisted till the end of the Albian.

The coincidences of thermokappametric and biostratigraphic units, registered in the Aptian-Albian beds from Dagestan (Appendixes 5, 6), seem quite logical. The changes in the redox potential of the deposition environment, as well as the hydrogen-sulphide contamination, are known to be controlled by palaeoclimate features and eustatic oscillations. The same factors influence biota evolution and the relationship between planktonic and benthic organisms in the palaeobasin. Thus, vertical distributions of the dk's, document the changes of faunal sequences within the sections considered.

As shown in Figure 4, the values of k and dk demonstrate obvious reverse relationships: the highly magnetic Hauterivian-Barremian parts of the sections are characterised by minimal increases of magnetic susceptibility, while, on the contrary, the highest dk values are recorded in the low magnetic Aptian-Albian sequences. The negative correlations between the k and dk diagrams are accounted for by the oxidising environment in the palaeobasin during the periods of tectonic activations, and by the favourable conditions for reducing settings in the deep parts of the reservoir during the periods of tectonic stabilisation.

CONCLUSION

The set of geologic and petromagnetic data provides the grounds for subdividing the Lower

Cretaceous Stage in the development of the North Caucasian Region into three steps, reflecting peculiar geodynamic and geochemical settings in various intervals of geologic time.

The first one, the Berriasian-Valanginian step, is peculiar for mainly carbonate deposition. The insignificant amount of detritus in the Berriasian deposits, and its almost complete absence from the Valanginian sequences, are indicative of quiet palaeotectonic settings and low erosion bases both, in the Southern, and the Northern lands.

The second, the Hauterivian-Barremian step, was characterised by intensive terrigenous drift against the background of general tectonic activation. The central part of the Great Caucasus becomes then one of the principal sourcelands, with fairly commonly developed granite and basite bodies – the main suppliers of magnetic materials to the region of marine accumulation. The Hauterivian-Barremian tectonic activation of the Great Caucasus might be a regional reflection of the final stage of the Late Kimmerian tectogenesis phase (Kunin & Sardonnikov 1976).

The third one, the Aptian-Albian step, coincides with tectonic stabilisation of the region associated with further northward transgression development. The Great Caucasus then has probably lost its importance as a supplier of terrigenous material, and the marginal regions of the Scythian Plate have once more become the principal distributive provinces. During that stage, the deposition was taking place in reducing hydrogen-sulphide settings. A correspondence can't be ruled out between the noted peculiarity of the Lower Cretaceous palaeogeochemistry in the basin, and the global anoxic events at the Early/Late Cretaceous boundary (Dale *et al.* 1992).

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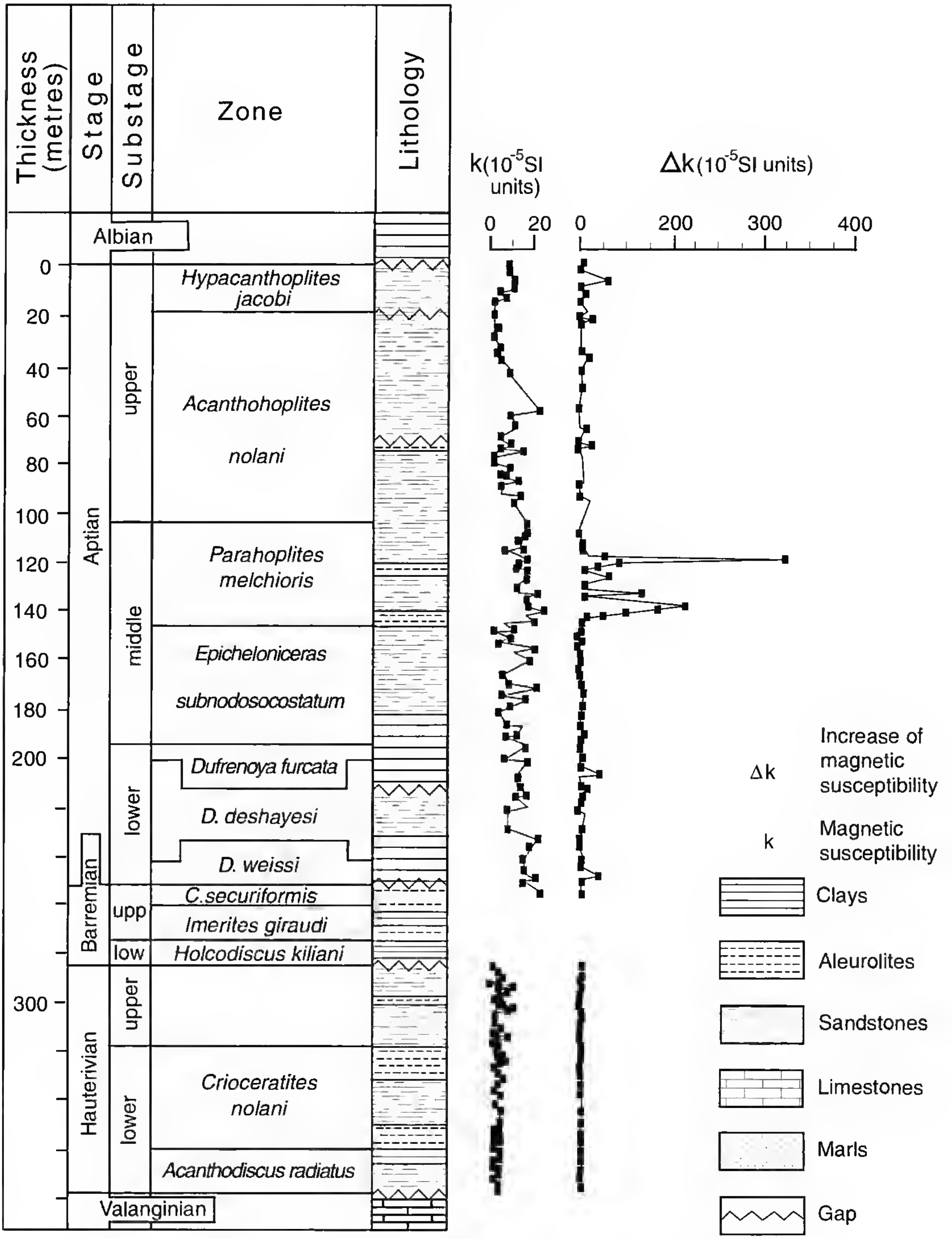
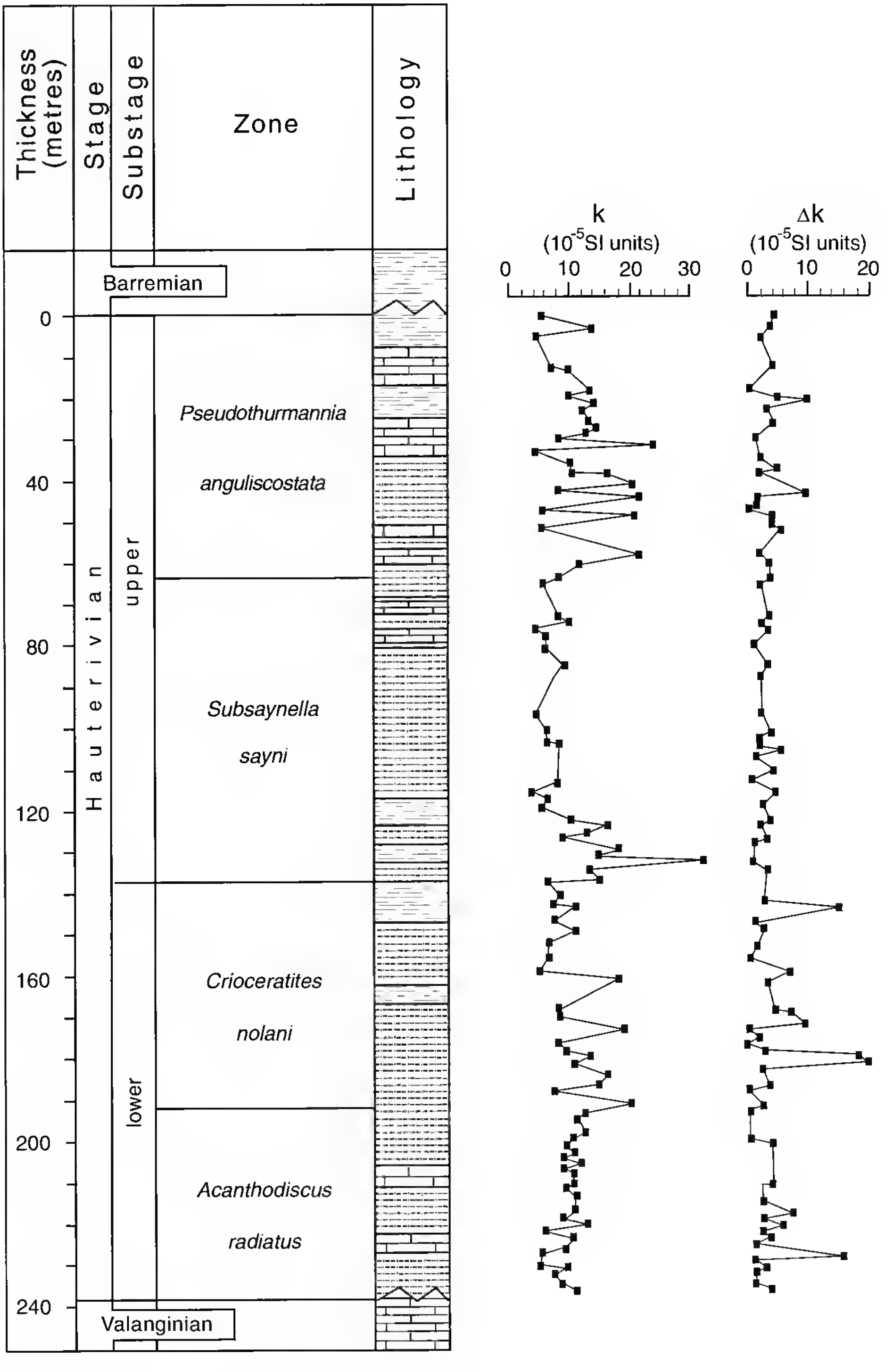
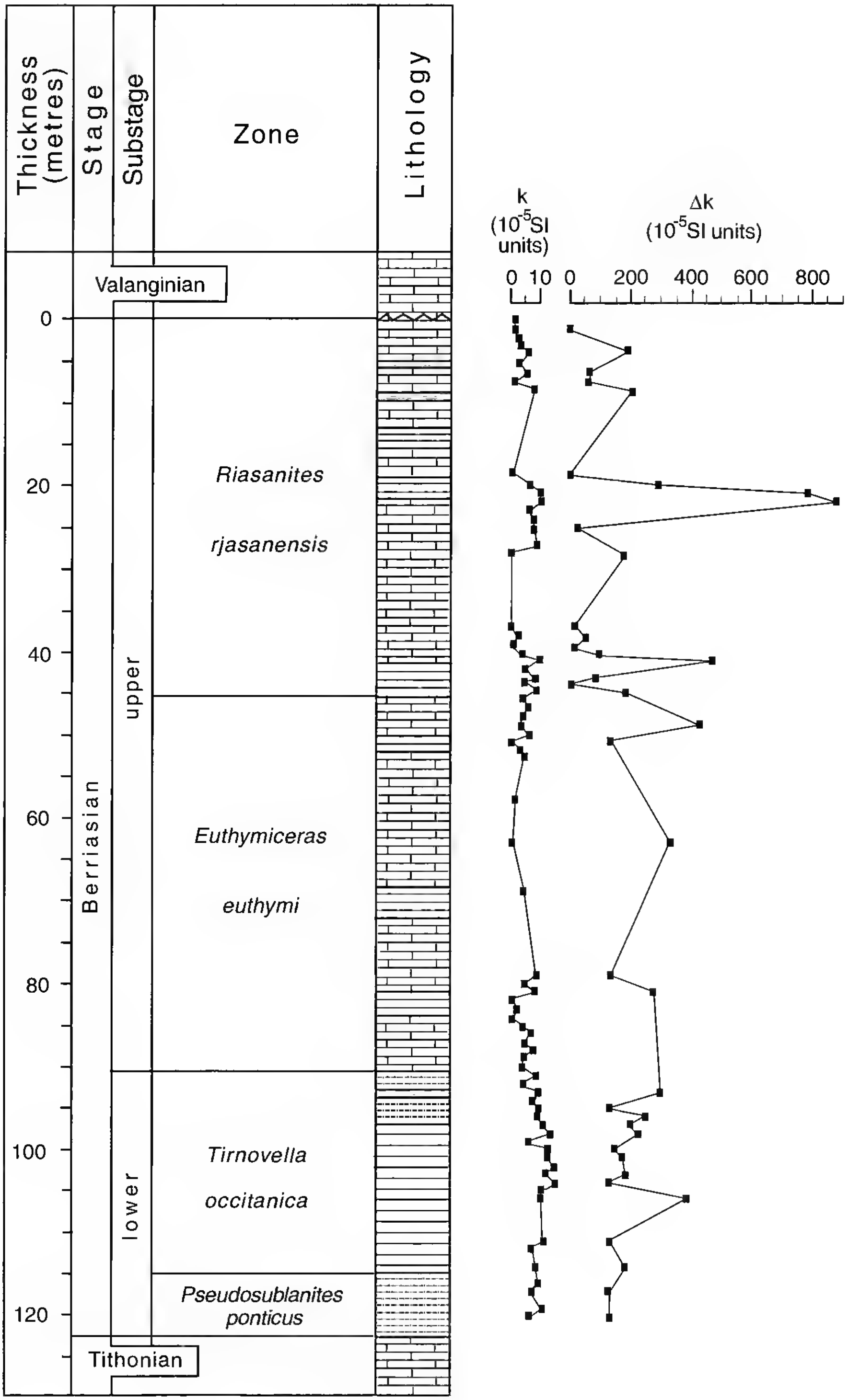
APPENDIX



APPENDIX 1. — Petromagnetic characteristics of the Hauterivian-Aptian deposits from Kislovodsk Section.

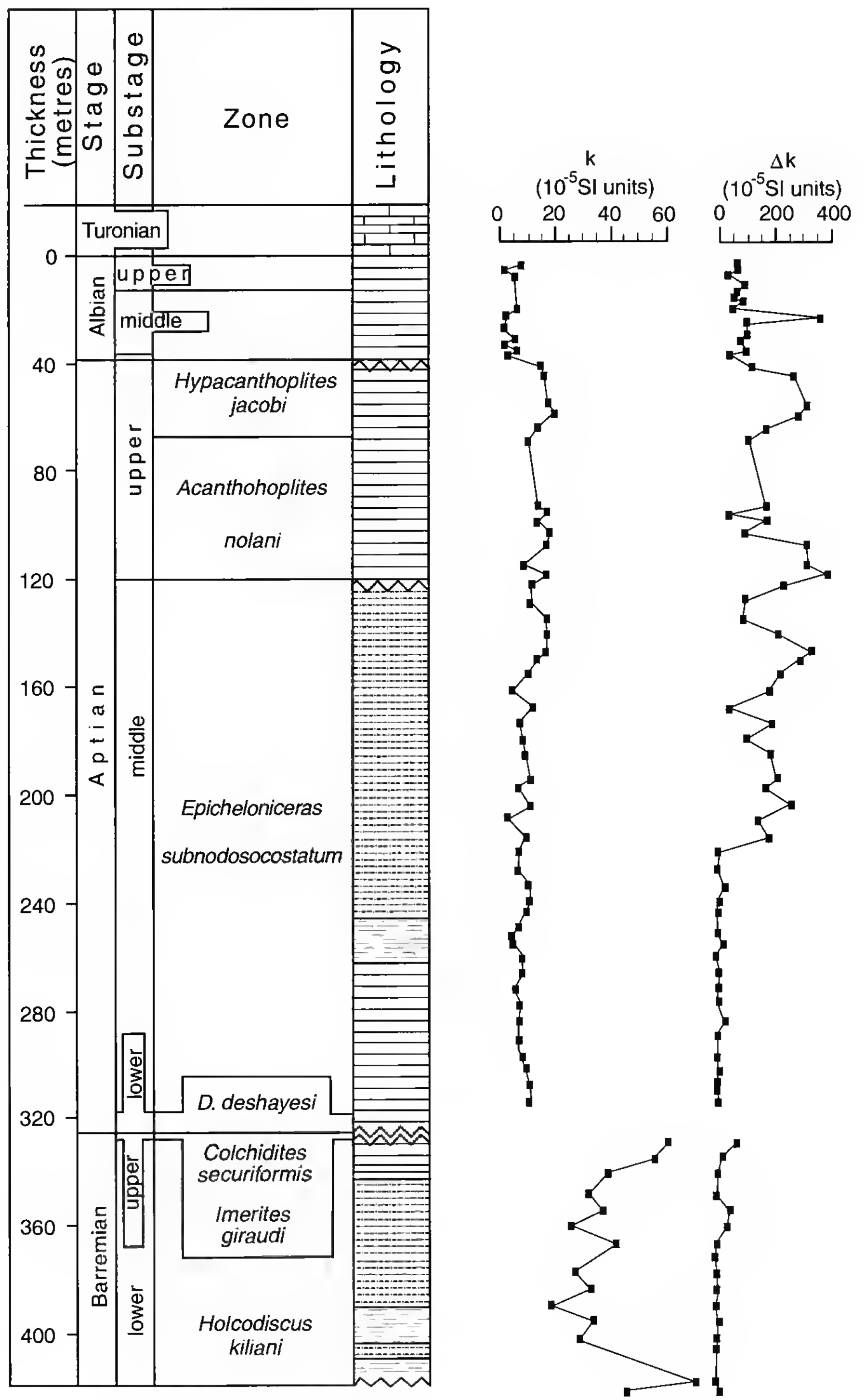


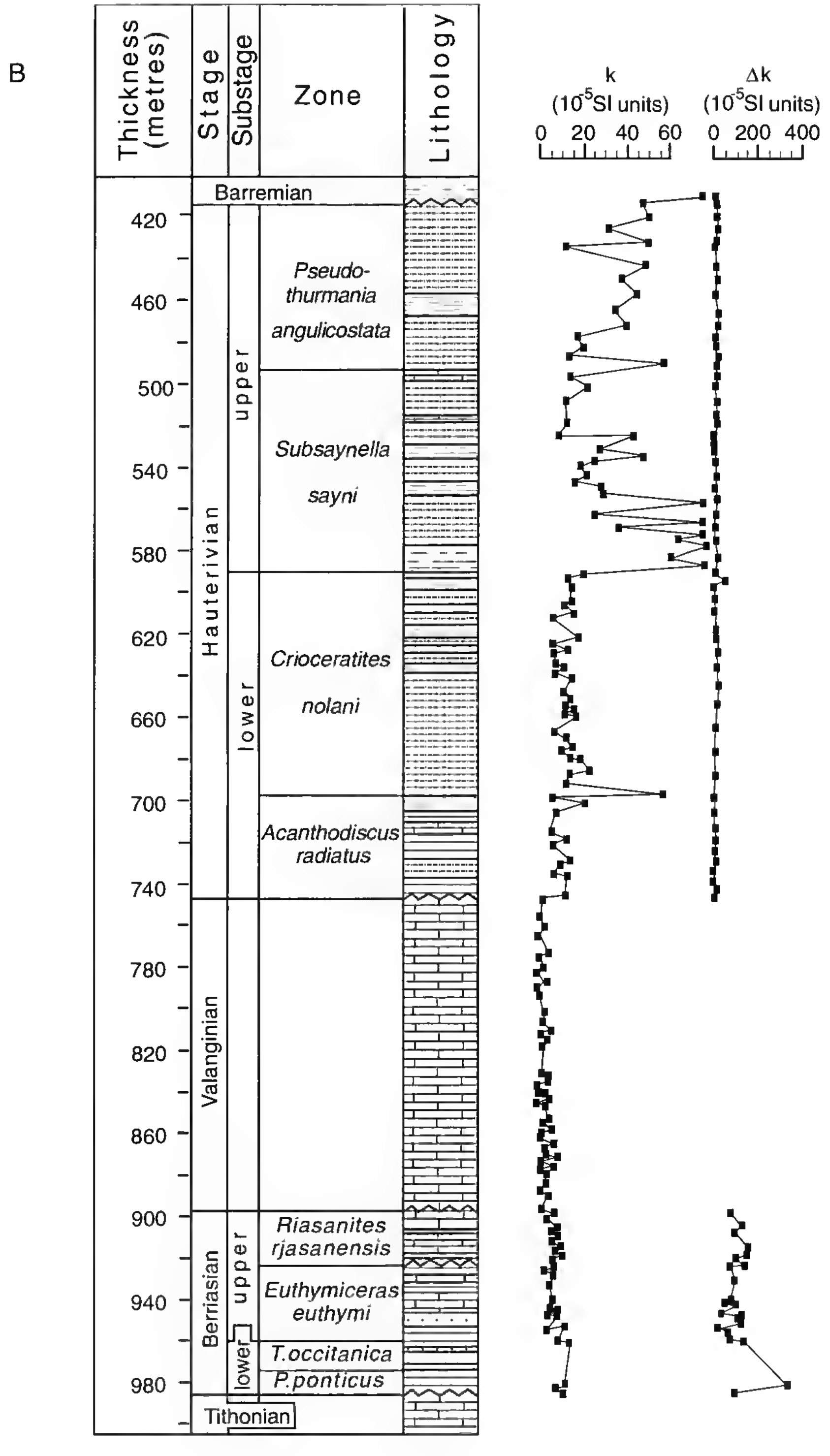
Appendix 2. — Petromagnetic characteristics of the Hauterivian deposits from Baksan Section. For legend of lithology and gap, see Appendix 1.



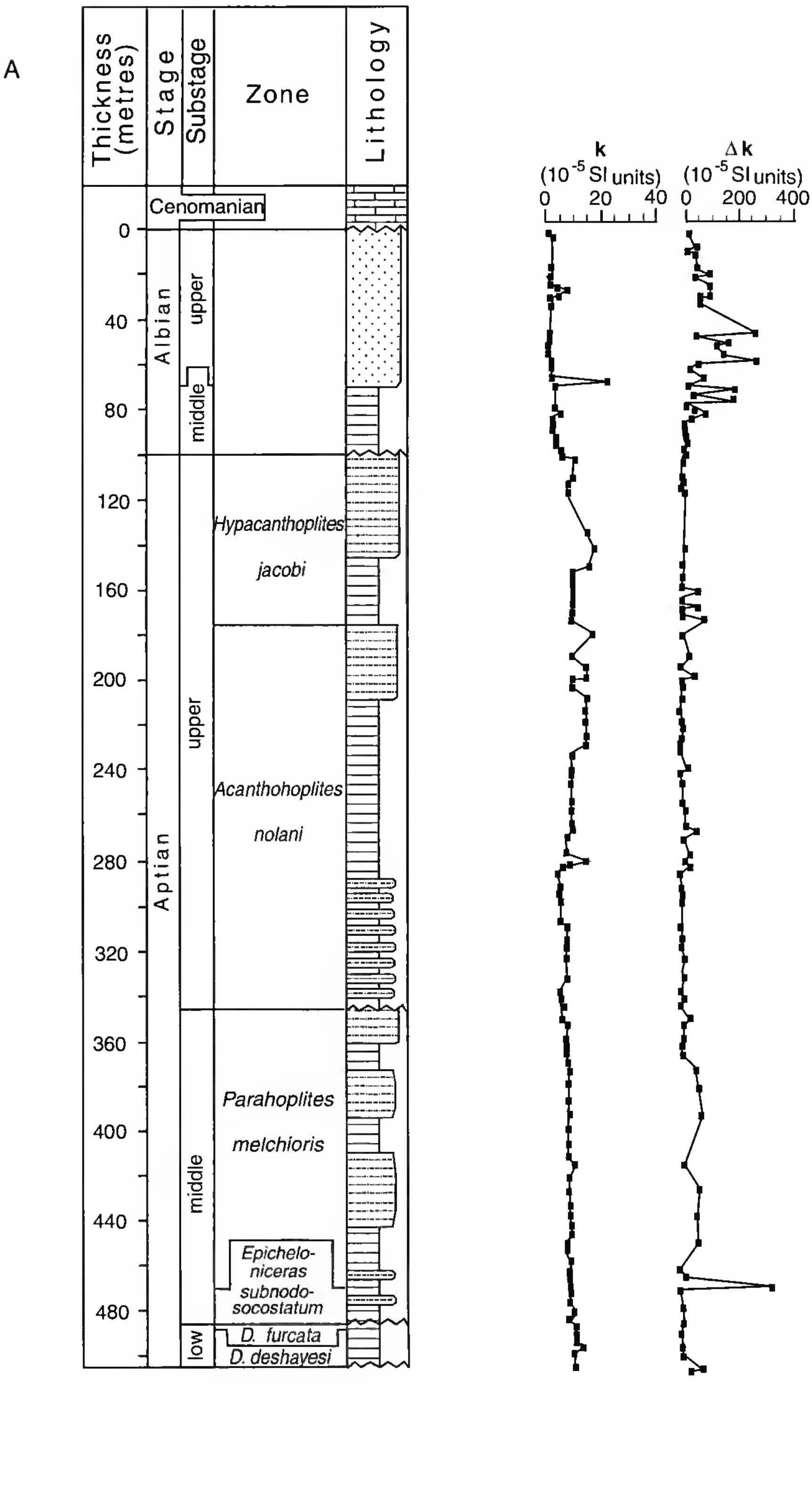
Appendix 3. — Petromagnetic characteristics of the Berriasian deposits from Assa Section. For legend of lithology and gap, see Appendix 1.

A

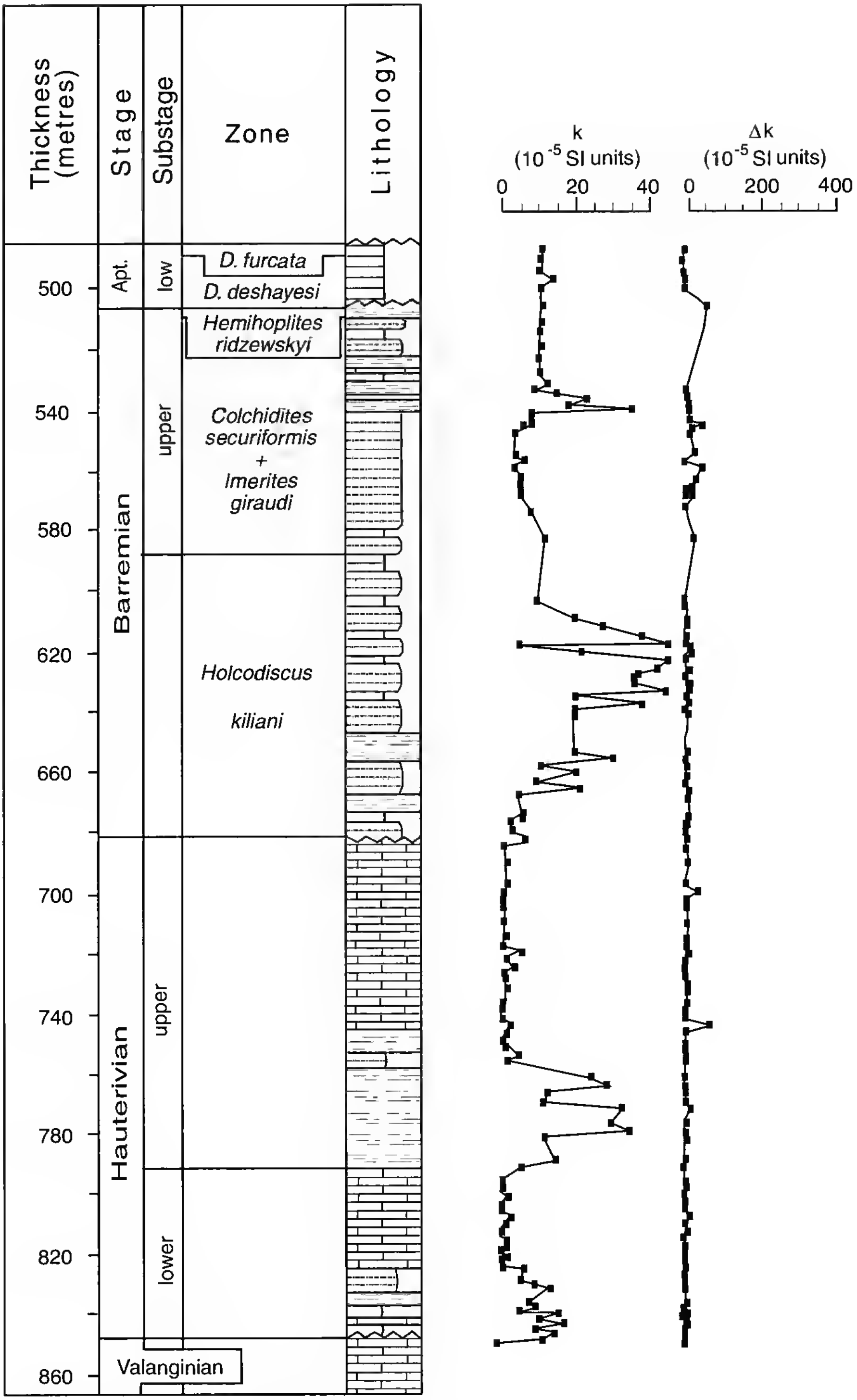

Thickness (metres)
Stage
Substage
Zone
Lithology
k
(10^{-5}SI units)
0 20 40 60
Δk
(10^{-5}SI units)
0 200 400
Turonian
0
upper
Albian
middle
40
Hypacanthoplites jacobi
80
upper
Acanthohoplites
nolani
120
160
Aptian
middle
200
Epicheloniceras
subnodosocostatum
240
280
lower
D. deshayesi
320
Colchidites securiformis
upper
Imerites giraudi
360
Barremian
lower
Holcodiscus kiliani
400



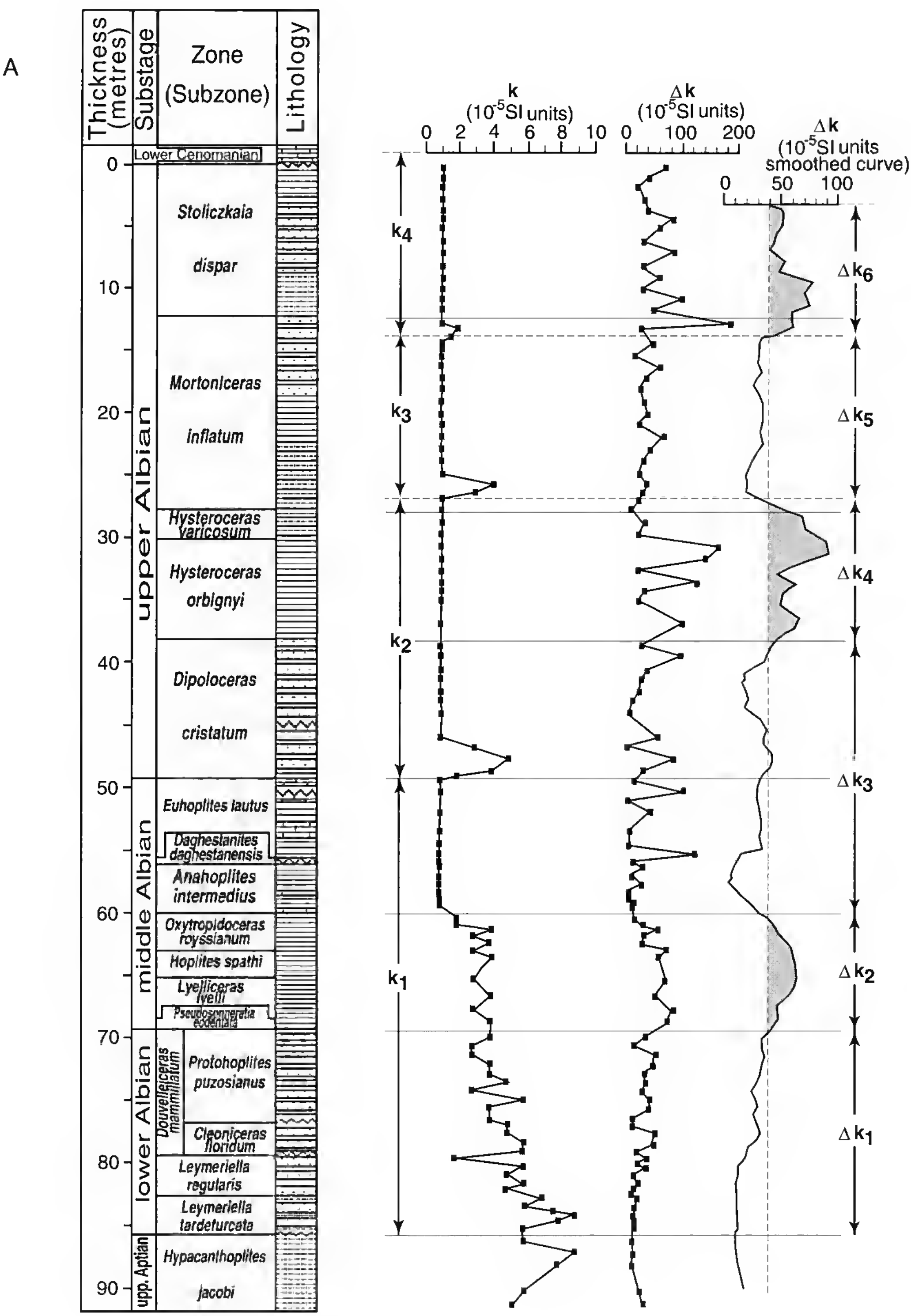
APPENDIX 4. — **A**, **B**, petromagnetic characteristics of the Berriasian-Albian deposits from Urukh Section. For legend of lithology and gap, see Appendix 1.

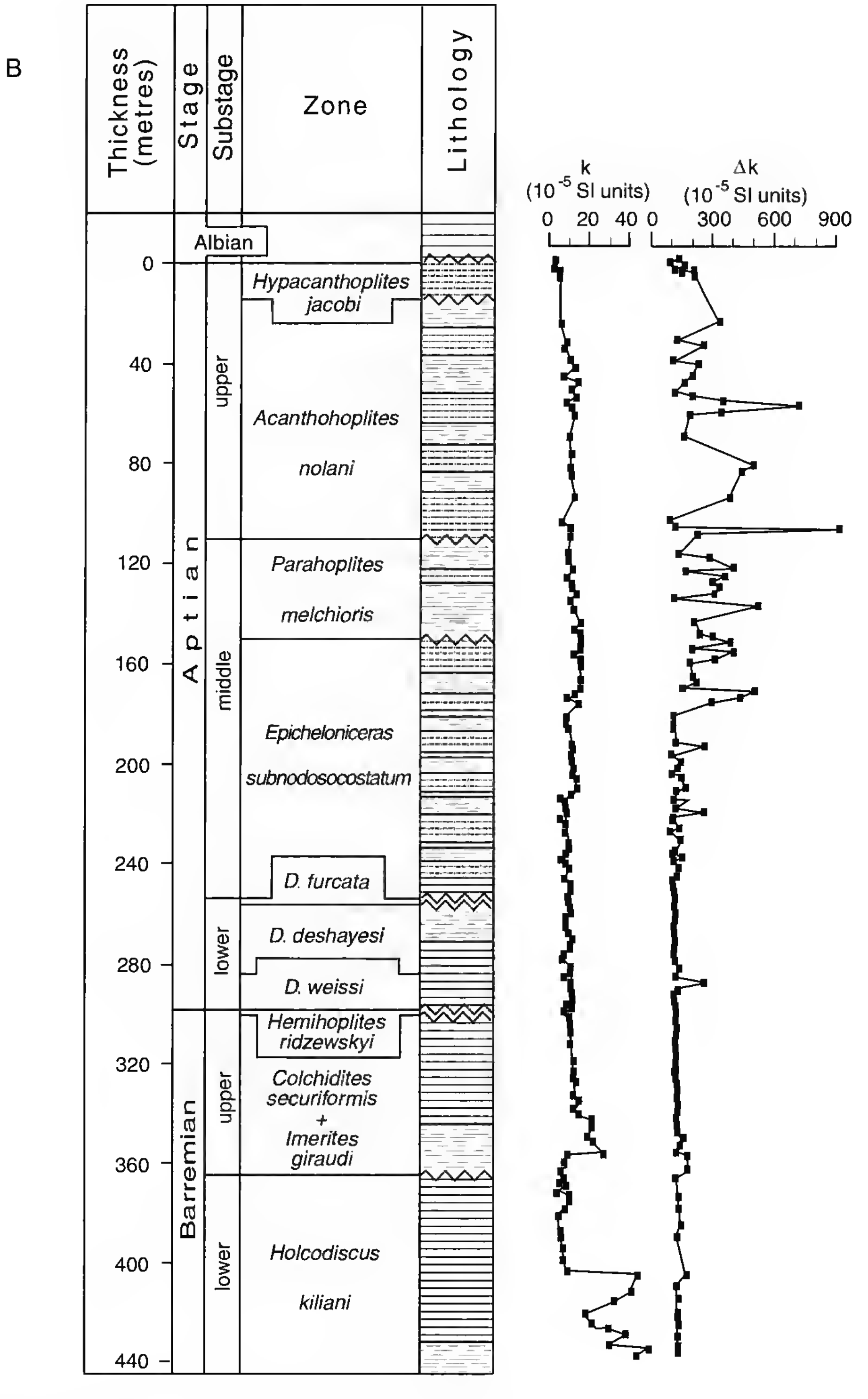

A
Thickness (metres)
Stage
Substage
Zone
Lithology
Cenomanian
Albian
upper
middle
Aptian
upper
middle
low
Hypacanthoplites jacobi
Acanthohoplites nolani
Parahoplites melchioris
Epicheloniceras subnodosocostatum
D. furcata
D. deshayesi
0
40
80
120
160
200
240
280
320
360
400
440
480
k
(10^{-5} SI units)
0 20 40
Δk
(10^{-5} SI units)
0 200 400

B



APPENDIX 5. — **A**, **B**, petromagnetic characteristics of the Hauterivian-Albian deposits from Gergebil Section. For legend of lithology and gap, see Appendix 1.


A
Thickness (metres)
Substage
Zone (Subzone)
Lithology
Lower Cenomanian
upper Albian
middle Albian
lower Albian
upp. Aptian
Stoliczkaia dispar
Mortoniceras inflatum
Hysteroceras varicosum
Hysteroceras orbignyi
Dipoloceras cristatum
Euhoplites lautus
Daghestanites daghestanensis
Anahoplites intermedius
Oxytropidoceras roissyanum
Hoplites spathi
Lyelliceras lyelli
Pseudosonneratia eodentata
Douvilleiceras mammillatum
Protohoplites puzosianus
Cleoniceras floridum
Leymeriella regularis
Leymeriella tardefurcata
Hypacanthoplites jacobi
k (10-5SI units)
Δk (10-5SI units)
Δk (10-5SI units smoothed curve)
k4
k3
k2
k1
Δk6
Δk5
Δk4
Δk3
Δk2
Δk1



APPENDIX 6. — **A**, **B**, petromagnetic characteristics of the Barremian-Albian deposits from Akusha Section. For legend of lithology and gap, see Appendix 1.

Regional magnetic zonality scheme for the Berriasian-lower Aptian from the North Caucasus

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ABSTRACT

Palaeomagnetic research was carried out in the North Caucasus, Azerbaijan, Mountainous Mangyshlak and Central Kopetdag. The ten most complete marine sections of the Lower Cretaceous were selected. They provided opportunity to make reliable references of palaeomagnetic columns to the ammonite zones from the general stratigraphic scale. About 7500 oriented samples were selected from outcrops. The data on the Berriasian-lower Aptian deposits magnetism in the North Caucasus and the Western Central Asia combined with other authors data provide the material for revision of Neocomian palaeomagnetic structure.

KEY WORDS
Magnetostratigraphy, polarity, remanent magnetisation, Lower Cretaceous, Caucasus.

RÉSUMÉ

Zonation magnétique régionale pour le Bérriasien-Aptien inférieur du Nord Caucase.

Des recherches paléomagnétiques ont été poursuivies dans le Nord Caucase, en Azerbaïdjan, dans les montagnes du Mangyslhak et dans le Kopetdag central. Les dix coupes les plus complètes du Crétacé inférieur ont été sélectionnées. Elles offrent la possibilité de dresser des colonnes paléomagnétiques de référence, corrélables aux échelles standard d'ammonites. Environ 7500 échantillons orientés ont été prélevés. Les données sur le magnétisme des dépôts du Berriasien-Aptien inférieur dans le Nord Caucase et l'Asie centrale de l'Ouest, combinées avec les données bibliographiques, permettent une révision de la structure paléomagnétique du Néocomien.

MOTS CLÉS
Magnétostratigraphie, polarité, aimantation rémanente, Crétacé inférieur, Caucase.

INTRODUCTION

The materials obtained constituted the basis for a composite section of the Berriasian-lower Aptian of the North Caucasus; four relatively large magnetozones with alternating, normal and mainly reverse polarity were recorded within this section. Their stratigraphic ranges (stage, substage) correspond to the orthozones from the general palaeomagnetic scale (Anonymous 1992). Each orthozone is characterised by a rather complicated structure owing to subordinate sub- and microzones of opposite polarities.
Palaeomagnetic units, which contrary to palaeontological ones, are stable on global scale, in certain cases may be used as a measuring rule for parallelisations of stratigraphic scales from distant regions.
Magnetostratigraphic correlation of the Berriasian deposits from the Caucasus and the stratotype region has made it possible to reveal the interrelations between the ammonite scales from the two regions, and furthermore, to establish the approximate locations of calpionellid-zone boundaries in the sections on the Caucasus.
Correlations of magnetostratigraphic sections from Mangyshlak, the northern Mediterranean and the English hypostratotype made it possible to consider the correlations between the ammonite and calpionellid scales of the Valanginian.

WORKING METHODS

The study was focused on the most complete Berriasian-lower Aptian marine sections from the North Caucasus and Central Kopetdag (Fig. 1) providing reliable referencing of the palaeomagnetic columns to the ammonite zones in the general stratigraphic scale.
The sections were commonly described in cooperation with biostratigraphers, which allowed strict geologic and palaeontologic control of the palaeomagnetic arrangements.
Frequencies of the oriented sample selection were determined by the thicknesses of the deposits studied. Sampling intervals varied from 0.5 to 3.5 m in the sections through folded areas and from 0.2 to 0.75 m in the platform.
As a rule, one sample was selected from each stratigraphic level; later on, it was sawed in 4-6 cubes, 24 or 20 mm on edges.
Palaeo- and petromagnetic studies were accompanied by the standard complex of laboratory work. Magnetic susceptibilities (k) and natural remanent magnetisation (NRM, Jn) were measured; magnetic cleaning was carried out with temperatures and alternating magnetic fields; normal magnetisation curves were drawn with subsequent measuring of the remanent saturation magnetisation (Jrs), determination of saturation fields (Hs) and destroying fields of remanent saturation magnetisation (H'cs). Thermomagnetic and differential thermomagnetic analyses (TMA and DTMA) were widely used to diagnose magnetic phases. A number of samples from each section were studied by means of optical mineralogy.
Remanent magnetisations were measured by ION-1, JR-3, JR-4 devices, magnetic susceptibilities – by IMV-2 and KT-5.
Temperature magnetic cleaning was performed in the non-magnetic furnaces within four or five-layer permalloy screens or within a Helmholtz ring unit. Successive heating was carried out in the range of 100-500 °C at temperature increment of 50-100 °C during one to four hours. To consider possible rock biasing, at least two cubes from each sample were put into the furnace: those with mutually antithetic orientations in all the three components of magnetisation vectors.
Some samples underwent cleaning with alternating magnetic field within Helmholtz ring system in the range of $16\text{-}40.10^{-3}$ A/m.
The analyses of normal magnetisation parameters (Hs, Jrs, H'cs) and the TMA and DTMA data (See fig. 2 *in* Guzhilov & Molostovsky, this volume) make it possible to conclude, that magnetisation of the rocks studied, was caused mainly by magnetite. Its presence is easily diagnosed by means of thermomagnetic curves: remanent magnetisation vanishes from the region of 580 °C (magnetite Curie point). The sample magnetic saturations have revealed the magnetically soft phase typical of finely dispersed magnetite (Hs = $32\text{-}64.10^{-3}$ A/m, H'cs = $24\text{-}50.10^{-3}$ A/m).
Zijderveld diagrams were constructed for com-

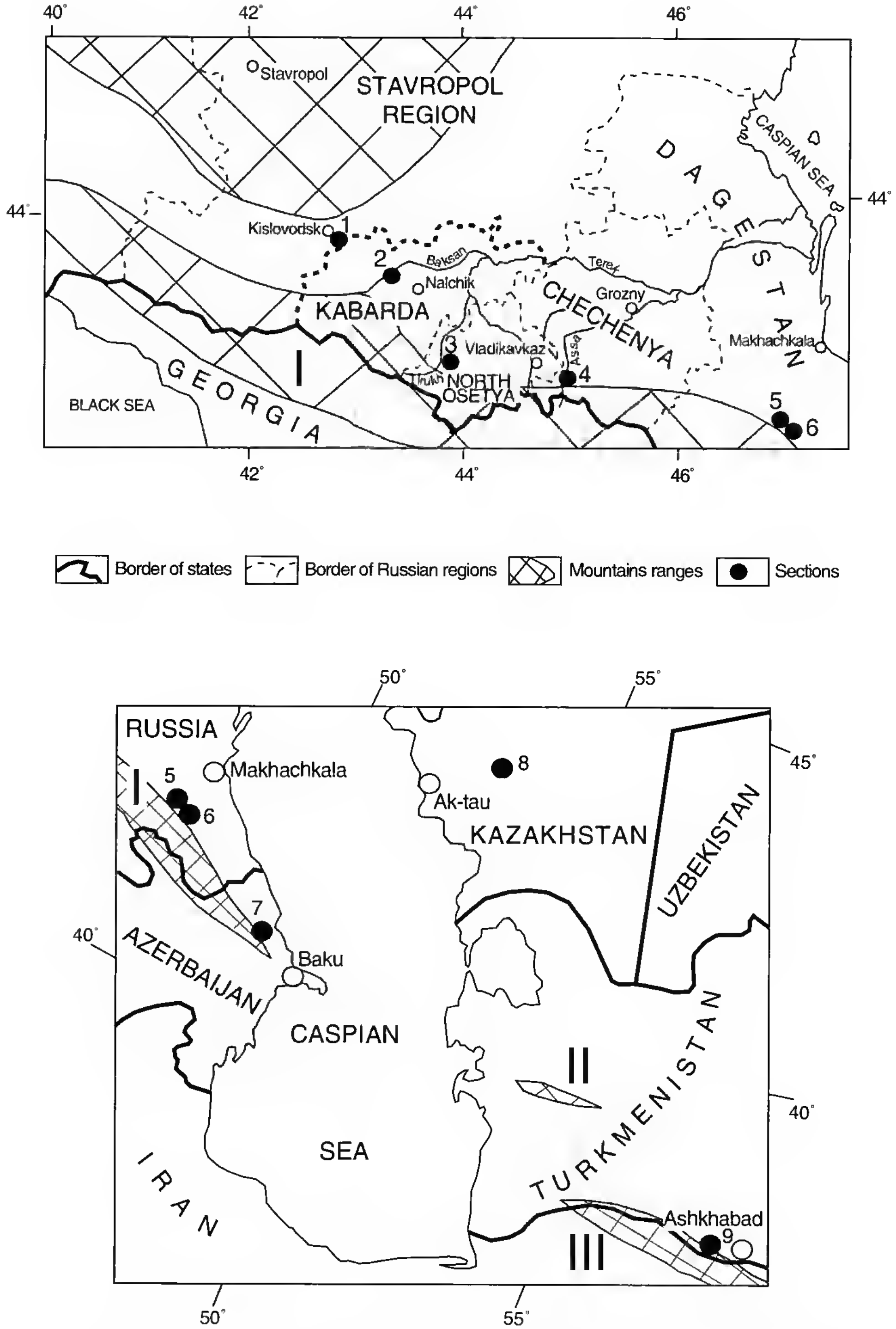


FIG. 1. — Location map. **I**, Great Caucasus; **II**, Balkhan; **III**, Kopet-Dag. Sections: **1**, Kislovodsk City; **2**, the Baksan River; **3**, the Urukh River; **4**, the Assa River; **5**, Gergebil Village; **6**, Akusha Village; **7**, Nardaran Village (Northern Azerbaijan); **8**, Tyuyesu Mountains (Mangyshlak); **9**, the Segiz-Yab River (Central Kopetdag).

ponent analyses of remanent magnetisation vectors. The typical diagram presented in Figure 3, testifies to the stability of resulting Jn trends: over the whole temperature interval after destruction of the secondary components, the vector changes along the straight line directed towards the centre of co-ordinates.

Magnetisation of the rocks considered, is characterised by two components: the primary one, revealing its trend after mild thermal cleaning and preserving it up to 500 °C (Fig. 2), and the secondary one, of probable viscous nature. The latter fact is affirmed by the majority of Jn vectors clustering after in situ measurements about the trend of rock remagnetisation by the present field (Appendix 1A). After a series of successive t°- and H-cleanings, the remagnetisation trends were regularly clustering in the first quadrant of the lower hemisphere or in the third quadrant of the upper one (Appendix 1B). These sets were interpreted as the normal and reverse polarity intervals, respectively.

To substantiate the Jn priority, numerous geologic-geophysics criteria and tests were applied, which made it possible to judge the age of magnetisation in major rock complexes. Some of these indications are considered below.

1. One of the important indications of a Jn sign being related with the polarity of an ancient field, consists in orientation independence of magnetisation vectors upon lithologic-mineralogic characteristics. In the majority of the sections studied, the magnetisation trends are obviously indifferent to various rock types (Appendixes 3-8).

2. Another evidence of magnetisation priority lies in the lack of interrelations between polarity signs and scalar magnetic characteristics. In many sections studied, several diverse-polarity zones were recognised within sequences undifferentiated with respect to k or Jn. Similar situation is observed, for instance, in the Valanginian beds on the Tyuyesu Mountain (Appendix 3). In the Barremian section near the village of Gergebil, on the contrary, a normal polarity zone embraces both, the weakly magnetised (k = 3-10.10^{-5} SI units, Jn = 0.5-1.2.10^{-3}/m), and strongly magnetised (k = 20-50.10^{-5} SI units, Jn = 2-4.10^{-3} A/m) intervals (Appendix 4).

3. The immersional analyses data show allothigenic magnetite to be present in the rocks. The coarsest Fe_3O_4 varieties have angular grains with obvious signs of transportation by water (scratches and grooves on faces and edges), which confirms their terrigenous origin. To a certain extent, this arguments for detrital nature of magnetisation. Firm grounding of this statement is identical to NRM priority proof.

Low values of Kenigsberger ratios (Q = Jn/Ji = 0.05-0.5) and low inter-sample clustering of the trends of stable NRM components (k = 5-30), characteristic of DRM (or PDRM), are regarded as the indirect palaeomagnetic evidences in favour of orientational (or postorientational) genesis of magnetisation.

4. Correlation of the palaeomagnetic structures of the similar-aged beds from distant heterofacial sections, may certainly serve as a strong argument for substantiating the geophysical nature of magnetozones. The overwhelming majority of the magnetozones recognised, meet this criterion and are laterally traced in certain stratigraphic intervals within various lithological-magnetic rock types that have been formed in diverse geochemical settings (Fig. 3). It is practically impossible to imagine, that self-reversal or secondary remagnetisation processes, able to result in distortion of NRM polarity, may be manifested synchronously over vast territories and in rocks of diverse types. The indication of exterior correlation becomes especially ponderable when similar magnetic polarity zones are recognised within similar-aged stratigraphic intervals from the regions characterised by different geologic histories. For example, the reverse polarity subzone R_1ap is recognised in the base of the lower Aptian substage, both in the North Caucasus and in the Kopetdag. The comparisons of the palaeomagnetic columns from the objects studied with the magnetostratigraphic sections from Siberia, Central Asia, West Europe and other regions lying apart (Fig. 3), have revealed good correlation of the palaeomagnetic data.

Each of the above criteria indirectly confirms, but does not prove priority of Jn. An important evidence in favour of this hypothesis, however, lies in the sum of independent observations conforming to the suggesrion of the ancient nature of NRM.

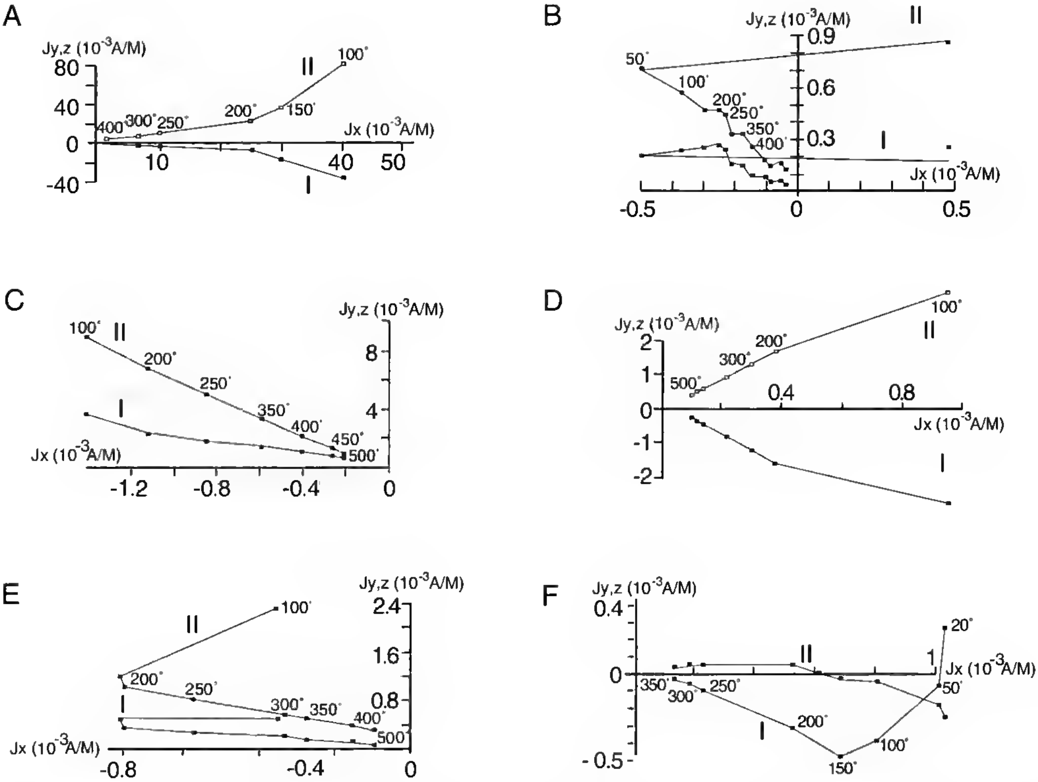


FIG. 2. — Zijderveld diagrams. NRM vector projection in horizontal (I) and vertical planes (II) within the sample coordinate system. Samples: **A**, clay (Hauterivian, Gergebil Village); **B**, limestone (Hauterivian, Gergebil Village); **C**, aleurolite (Berriasian, the Urukh River); **D**, aleurolite (Barremian, Gergebil Village); **E**, aleurolite (Barremian, the Segiz-Yab River); **F**, sandstone (Aptian, Kislovodsk city).

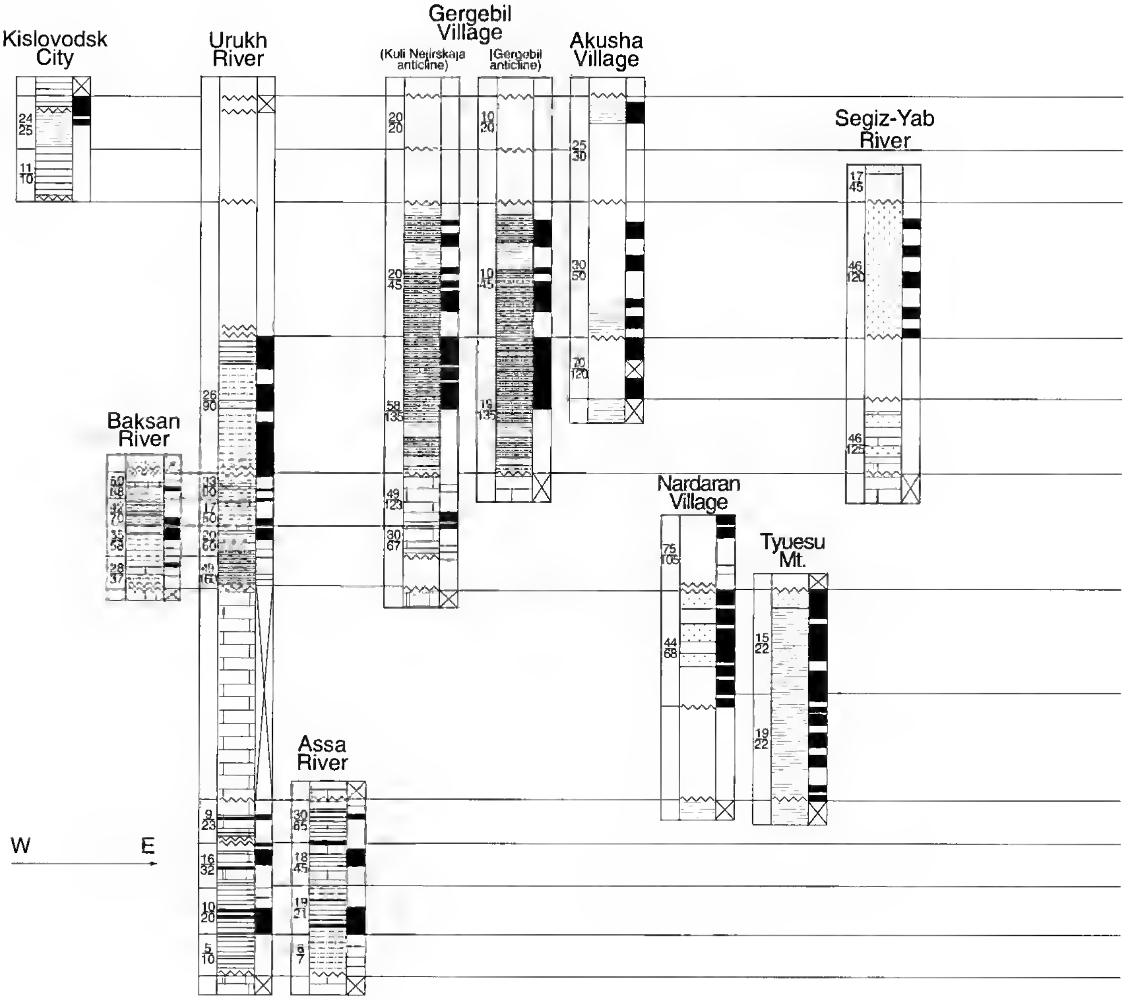
REGIONAL SCHEME OF THE NEOCOMIAN (BERRIASIAN-LOWER APTIAN) MAGNETIC ZONALITY IN THE NORTH CAUCASUS

The working magnetostratigraphic scheme of the Lower Cretaceous in the North Caucasus (Fig. 3) is based on palaeomagnetic study results from ten outcrops of the marine Lower Cretaceous; their geographic positions are presented in Figure 1. In all sections, the magnerozones recognised were reliably referenced to the ammonite zones in the general stratigraphic scale (Fig. 4), compiled from the data provided by numerous researchers (Prozorovsky 1989). On the total, the magnetostratigraphic scheme is characterised by ~7500 oriented samples from more than 1600 stratigraphic levels.

Composite palaeomagnetic columns for each of the Lower Cretaceous stages are described below. In conclusion, generalised characteristic of the regional Neocomian magnetic scheme is presented for the North Caucasus.

THE BERRIASIAN STAGE

The Berriasian beds, represented by alternating carbonate (limestones, marls) and terrigenous (clays, aleurolites) rocks, were studied in the North Caucasus on the Assa and Urukh rivers (Eremin 1991) (Fig. 4). In the first section, Sakharov (1976) has established all the ammonite zones of the Berriasian: each of them, except *Pseudosubplanites ponticus* zone, is further subdivided into two subzones. On the Urukh River, according to the finds of the corresponding index species, *Tirnovella occitanica*, *Euthymiceras euthy-*



mi and *Riasanites rjasanensis* zones were recognised (the *P. ponticus* lower zone, was not found there).
The composite Berriasian magnetostratigraphic section from the North Caucasian Region consists of five alternating subzones: three ones of reverse polarity (R_1b, R_2b, R_3b) and two of normal polarity (N_1b, N_2b) (Eremin 1991) (Figs 3, 4).

The Valanginian Stage

Palaeomagnetic study of the Valanginian beds was performed in the Trans-Caucasia (northern Azerbaijan, near the village of Nardaran) (Eremin & Guzhikov 1991) and in Mangyshlak (in Tyuyesu Mountains) (Fig. 3, Appendix 3).
In the first section, the uppermost of the Babadagskaya suite was exposed, represented by terrigenous-carbonate flysch (marls, clays, aleurolites, sandstones). The Valanginian age of the rocks was determined on the basis of microfaunal data (Aliev 1965).
The Valanginian Stage in Tuyesu Mountains is represented mostly by fine-grained sandstones. The two substages are recognised according to

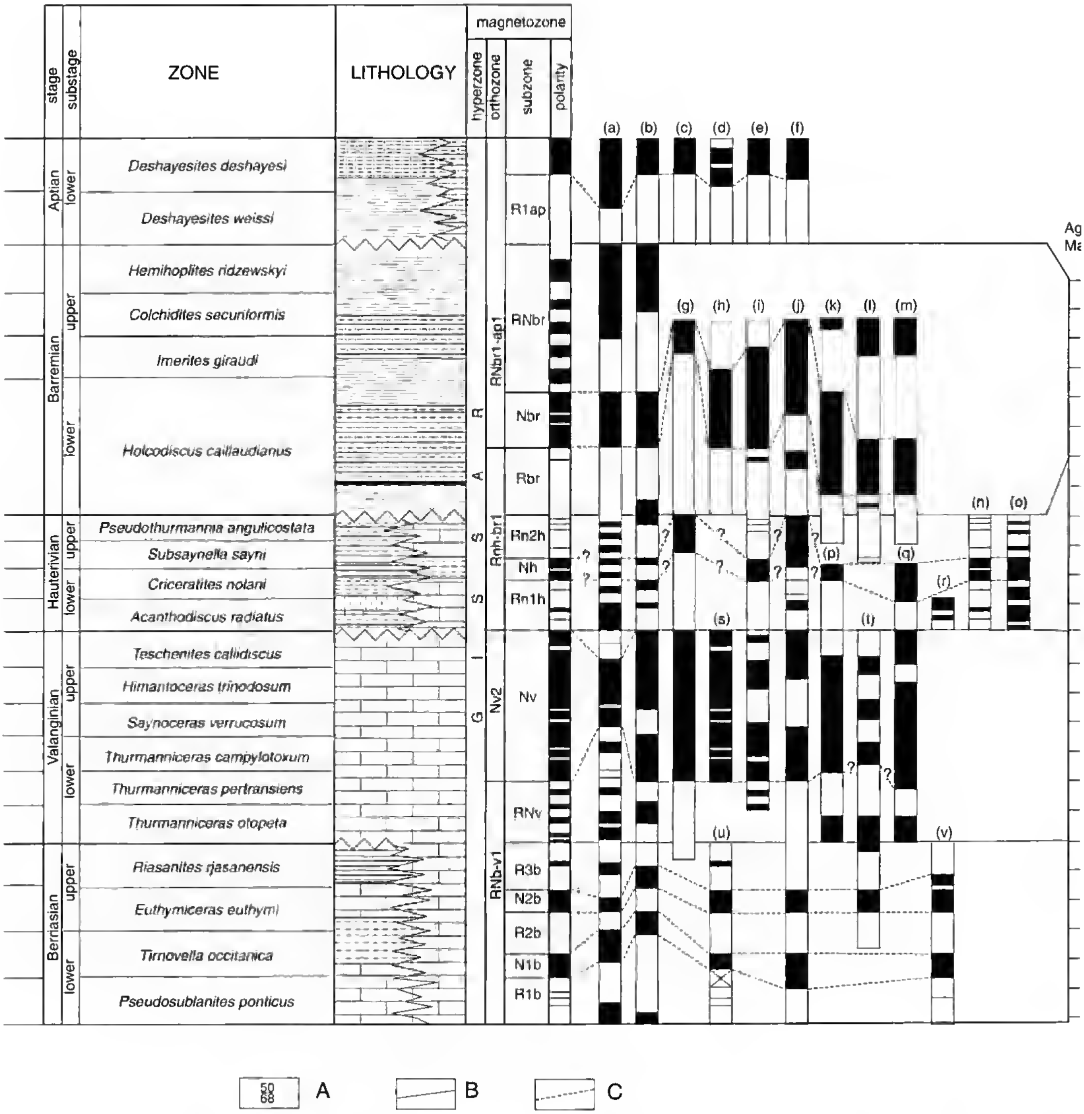


FIG. 3. — Regional magnetic zonality scheme for the Berriasian-lower Aptian from the North Caucasus. **A**, quantity of studied stratigraphic levels/Thickness (metres); **B**, correlative lines of biostratigraphic stages, substages and zones; **C**, correlative lines of palaeomagnetic subzones. Absolute age from Harland *et al.* (1982). **a**, Harland *et al.* (1982); **b**, Molostovsky & Khramov (1984) and Khramov (1982); **c**, Tarduno *et. al.* (1992); **d**, **j**, Pospelova (1976); **e**, **i**, Lowrie, Alvarez *et al.* (1980) and Lowrie, Channell & Alvarez (1980), **f**, Grishanov (1984); **g**, Pechersky (1970); **h**, Tretyak *et al.* (1976), **l**, Bralower (1987); **k**, Guseynov (1988); **m**, Channell *et al.* (1979); **n**, Ramazanov & Dedova (1990); **o**, Channell (1987); **p**, Ramazanov (1987), **q**, Rzhevsky (1968); **r**, Pospelova & Larionova (1971); **s**, Besse *et al.* (1986); **t**, Lowrie & Channell (1983); **u**, Galbrun (1985); **v**, Eremin (1991). For lithology, see legend on Appendix 4.

the macrofaunal complex, including ammonites (Bogdanova 1983).

The palaeomagnetic column of the Mangyshlak Section consists of two subzones: alternating (RNv) and normal (Nv) polarities. (Fig. 3, Appendix 3).

The Babadagskaya suite is encompassed by a major normal polarity magnetozone, complicated by five thin r-intervals (Eremin & Guzhikov 1991) (Fig. 3).

THE HAUTERIVIAN STAGE

The Hauterivian beds were studied on the Baksan and Urukh rivers, near the village of Gergebil (North Caucasus) and in the vicinity of Nardaran Village (northern Azerbaijan) (Eremin & Guzhikov 1991).

The first two sections are composed of clays, aleurolites and sandstones with subordinate marl and limestone interlayers. The Gergebil Section is represented by alternating terrigenous (clays, sandstones) and carbonate (limestones) members. The section near Nardaran consists of calcareous clays exclusively.

In the Central Cis-Caucasia (sections on the Baksan and Urukh rivers), deposits of all the Hauterivian biozones occur, which is confirmed by ammonite index species (Egoyan & Tkachuk 1965). In Gergebil, only the upper Haurerivian substage is recognised from ammonite fauna (Mordvilko 1960-1962). The underlying limestone sequence according to macrofauna is referred to the Hauterivian without further subdivision, and the lowermost section, devoid of organic remains, is referred to the Hauterivian Stage conventionally.

The Hauterivian age of the deposits near Nardaran is based on microfaunal data (Aliev 1965).

In each of the sections studied, three subzones were recognised: two of chiefly reverse (Rn) and one of normal (N) polarities (Eremin & Guzhikov 1991) (Fig. 3).

In the palaeomagnetic columns of all the four sections through the Hauterivian, despite its complexity, clear predominance of reverse polarity NRM is recorded (Fig. 4).

THE BARREMIAN STAGE

The Barremian beds were studied on the Urukh River, in the vicinity of Gergebil and Akusha (North Caucasus) and on the Segiz-Yab River (Central Kopetdag) (Fig. 3, Appendixes 4-7).

The Barremian from the North Caucasus is represented by sandstones, aleurolites and, to a lesser extent, by clays. The Kopetdag Section consists mainly of limesrones and marls.

In all the sections, both Barremian substages are recognised from the macrofaunal complex, ammonites included (Druzchiz & Michailova 1960; Mordvilko 1960-1962; Anonymous 1985). In the section of the Urukh, the upper Barremian deposits are condensed in a limestone layer 0.5 m thick.

The composite magnetostratigraphic section of the Barremian from the North Caucasus consists of three major subzones: those of reverse (R), normal (N) and alternating (RN) polarities (Fig. 3).

The palaeomagnetic column of the Kopetdag Section consists of two major subzones: those of reverse (R) and alternating (RN) polarities (Fig. 3, Appendix 7). The lower R-subzone corresponds to the lower half of the lower Barremian substage. The RNbr subzone encompasses the uppermost of the lower Barremian and the upper substage. The analogues of the North Caucasian normal polarity subzone are missing from the Segiz-Yab Section due to the early Barremian wash-out, that has not been previously recognised in this region, but is clearly pronounced in the adjacent Paroundag Range (Ammaniyazov *et al.* 1987).

THE LOWER APTIAN SUBSTAGE

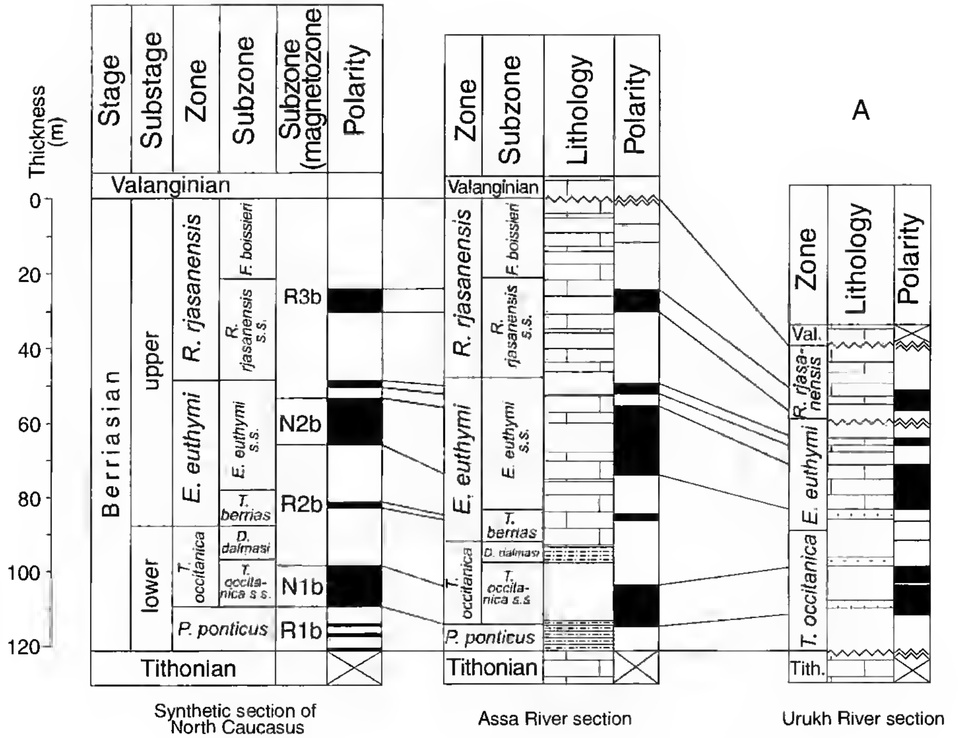
The lower Aptian deposits were studied in four sections: near the town of Kislovodsk, in the vicinity of Gergebil and Akusha (all in the North Caucasus) (Eremin & Guzhikov 1991) and on the Segiz-Yab River (Kopetdag).

The lower Aptian in the North Caucasus is represented by terrigenous rocks exclusively: sandstones, aleurolites and clays. In the Segiz-Yab Section, the lower Aptian consists mainly of aleurolites with subordinate interlayers of limestones, marls and sandstones. In the Volga Region, the lower Aptian structures are composed chiefly of clays and clayey sands.

The lower Aptian beds are saturated with ammonite fauna remains (Druzchiz & Michailova 1960; Mordvilko 1960-1962; Anonymous 1985; Moskvin 1986).

Only the lower Aptian *Deshayesites weissi* and *D. deshayesi* zones are palaeomagnetically sampled in the Caucasus.

On the Segiz-Yab, the ages of all the lower Aptian beds, accurare within substages, were substantiated by macrofauna (Ammaniyazov *et al.* 1987).



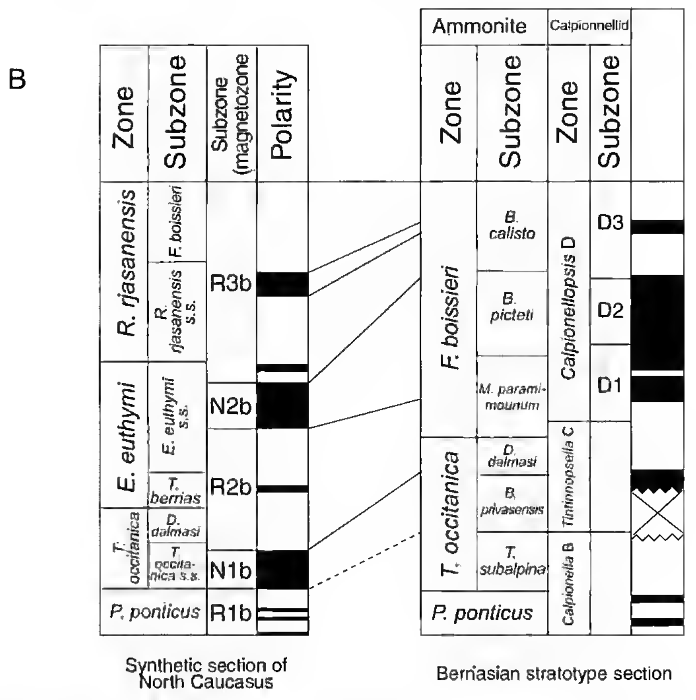


FIG. 4. — Magnetostratigraphical correlations of Berriasian deposits of North Caucasus (**A**) and between North Caucasus Region and the Berriasian stratotype section (**B**). For lithology, see legend on Appendix 4.

TABLE 1. — Correlations of the Berriasian ammonite scales from stratotype regions and North Caucasus.

North Caucasus after Druzchiz & Michailova 1960		Stratotype			North Caucasus after palaeomagnetic data	
Zone	Subzone	Zone	Subzone	Zone (calpionellides)	Zone	Subzone
Riasanites rjasanensis	*Fauriella boissieri*	*Fauriella boissieri*	*Berriasella callisto*	*Calpionelliopsis* (zone D)	*Riasanites rjasanensis*	*Fauriella boissieri*
	R. rjasanensis s.str.					*R. rjasanensis* s.str.
Euthymiceras euthymi	*E. euthymi* s.str.		*Berriasella picteti*		*Euthymiceras euthymi*	*E. euthymi* s.str.
	Tirnovella berriassensis		*Malbosiceras paramimounum*	*Tintinnopsella* (zone C)		*Tirnovella berriassensis*
Tirnovella occitanica	*Dalmasiceras dalmasi*	*Tirnovella occitanica*	*Dalmasiceras dalmasi*		*Tirnovella occitanica*	*Dalmasiceras dalmasi*
	T. occitanica s.str.		*Berriasella privasensis*			*T. occitanica* s.str.
			Tirnovella occitanica	*Calpionella* (zone B)	*Pseudosubplamites ponticus*	
Pseudosubplamites ponticus		*Pseudosubplamites grandis*				

In all the examined sections from the Caucasus and the Kopetdag, the lowermost Aptian is distinguished for a reverse polarity magnetozone (R_1ap) (Fig. 3, Appendixes 4-8). This magnetozone is stratigraphically equivalent to the *D. weissi* biozone, and the lower part of the *Deshayesites deshayesi*.

It may be seen from the correlation of the materials available (Fig. 3), that four relatively large zones of alternating, normal and chiefly reverse polarities correspond to the Lower Cretaceous portion in the composite palaeomagnetic section from the North Caucasus. The gap within the Valanginian part of magnetostratigraphic scale (no Valanginian beds were sampled in the North Caucasus) was eliminated owing to palaeomagnetic studies of the sections from Mangyshlak and Azerbaijan) (Fig. 3). Their stratigraphic ranges (stage, substage) correspond to the orthozones from the general palaeomagnetic scale (Anonymous 1992). Each orthozone is characterised by a rather complicated structure owing to subordinate sub- and microzones of opposite polarities.

The Lower Cretaceous palaeomagnetic scale opens with the alternating polarity orthozone RNb-v_1, embracing the Berriasian Stage and the lowermost lower Valanginian substage.

The normal polarity orthozone Nv_2 characterises the uppermost of the lower Valanginian and the upper Valanginian substage.

The chiefly reverse polarity orthozone, Rnh-br_1, comprises the Hauterivian stage and the base of the Barremian. The studies of the Hauterivian reference sections from the North Caucasus, have, for the first time, revealed the correspondence between the determined magnetozones and the ammonite zones of general stratigraphic scale.

The alternating polarity orthozone $RNbr_1$-ap_1 is stratigraphically equivalent to the uppermost of the lower Barremian, upper Barremian and lower Aptian.

COMPARISON OF THE REGIONAL AND GLOBAL DATA ON THE LOWER CRETACEOUS

The current ideas of the Lower Cretaceous magnetic zonality are based upon the data on linear magnetic anomalies, as well as upon fairly numerous, but unequally informative data on the Lower Cretaceous palaeomagnetism from various regions of Eurasia.

In the known models of the Phanerozoic general magnetostratigraphic scale (Khramov 1982;

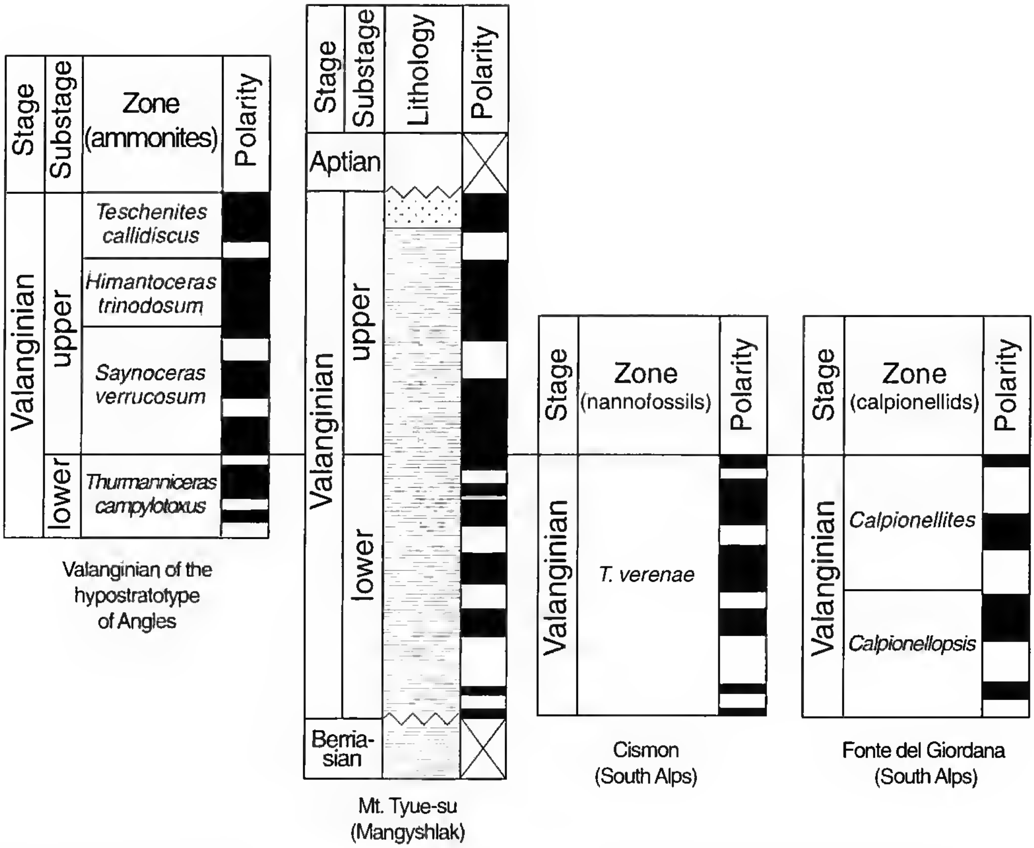


FIG. 5. — Magnetostratigraphical correlations between the Valanginian hypostratotype section of Angles (Besse *et al.* 1986), Mangyshlak Region and South Alps Region (Bralower 1987; Cirilli *et al.* 1984). For lithology, see legend on Appendix 4.

Molostovsky & Khramov 1984), as well as in the scale by Harland *et al.* (1982), the Lower Cretaceous is sharply differentiated into two parts. The Neocomian belongs to the alternating polarity interval, while the Aptian and the Albian stages correlate with the epoch of stable normal polarity field. Thus, the boundary between two major magnetostratones is established within the base of the Aptian: between the NR-Gissar and N-Djalal hyperzones (Khramov 1982; Molostovsky & Khramov 1984).

THE BERRIASIAN STAGE

The commonly accepted views upon the Berriasian magnetic zonality as an alternating polarity interval, are based on research results from various continents [the stratotype section from southern France included (Galbrun 1985)] and on the data from oceanic magnetometric surveys (Fig. 3).

The results of the present study are in complete accord with the ideas of sign-changing magnetic zonality of the Berriasian, with slight R-polarity prevalence.

Analogues of the palaeomagnetic zones distinguished by Galbrun (1985) in the Berriasian stratotype section (Fig. 4), are recognised the sequences from the Caucasus, which has made it possible to reveal the correlations among ammonite scales from the two regions, and, moreover, to record the approximate positions of calpionellid zones the Assa and Urukh sections.

The right side of Table 1 shows parallelization results for the Berriasian palaeontologic units from the stratotype and the North Caucasian regions (the left side of the Table, correlations

among ammonite biozones and subzones, previously accepted by palaeontologists, are given for comparison (Prozorovsky 1989).

The Valanginian Stage

The Valanginian magnetic zonality shows some problem. Alternating polarity is recorded in the scale of oceanic anomalies and in the North Mediterranean sections. At the same time, the data on the stage Angles hypostratotype (Besse *et al.* 1986) testify to the normal polarity dominance in the late Valanginian.

Comparisons of the Valanginian magnetostratigraphic sections from Mangyshlak, North Mediterranean (Cirilli *et al.* 1984; Bralower 1987) and the Angles stratotype, have made it possible, in the first place, to present an explanation for the reason of discord among magnetostratigraphic data on the Valanginian, and then to consider the interrelations among the ammonite and calpionellid scales of the stage.

In the South Alpine sections, provided with microfaunal grounding, the Valanginian is characterised by alternating polarity (Fig. 5). In the parastratotype and Mangyshlak sections, divided according to ammonites, an abnormal polarity orthozone corresponds to the upper substage (Fig. 5). An alternating polarity subzone (Fig. 5) corresponds to the lower Valanginian sequence in the Tyuyesu Mountains Section. Regretfully, the lower Valanginian deposits from England were not described in terms of magnetic polarity.

The above data considered, we may suppose the deposits from the *Calpionellites* zone and from the uppermost of the *Calpionelliopsis* in Umbria, to be analogous to the lower Valanginian substage. This inference is in agreement with Kent & Gradstein (1985) data on correlations between the Valanginian calpionellid and ammonite zones.

In the scale of linear magnetic anomalies, the largest normal polarity chron (M10N) is probably analogous to the Nv orthozone.

The Hauterivian Stage

The Hauterivian is characterised by sign-changing magnetic polarity.

The data on the Hauterivian palaeomagnetic structure in the Caucasus, is in accordance with Harland *et al.* materials on linear magnetic anomalies /90/, with those by Pospelova & Larionova (1971) from West Siberia, Ramazanov (1987) and Ramazov & Dedova (1980) from Turkmenia, Pechersky (1970) from north-east Russia, Bralower (1987) from South Alps. In all the listed regions, the Hauterivian palaeomagnetic columns show reverse over normal polarity dominance, and record at least eight magnetic field reversals (Fig. 3).

In the oceanic scale (Harland *et al.* 1982), the only major normal polarity chron (M4) is registered in the middle of the Hauterivian interval of the scale (Fig. 3). In the composite magnetostratigraphic section from the Caucasus, this may be analogous to the Nh subzone, associated with the substage boundary.

Polarity distributions within the North Italian Capriolo and Xausa sections, are a little bit different from the above sketch, according to Channell *et al.* (1979), normally magnetised rocks obviously prevail there (Fig. 3). This fact has not yet been unequivocally explained.

The Barremian Stage

According to the current views, the Barremian Stage is characterised by complex magnetic zonality (Fig. 3).

Our results on alternating magnetic polarity of the Barremian from the North Caucasus and Kopetdag, are, on the whole, in good accord with the data by Lowrie *et al.* (1980) and Bralower (1987) on the South Alpine sections of Umbria, Cismon, Gubbio, etc., with the lowermost of the stage corresponding to a probable analogue of the Rbr subzone (Fig. 3).

At the same time, according to Channell *et al.* (1987) definitions for the North Italian sections of Capriolo and Xausa major normal polarity magnetozones correspond to the lowermost of the Barremian Stage (Fig. 3).

The comparisons of the composite magnetostratigraphic section from the North Caucasus and Kopetdag with Harland *et al.* (1982) scale, do not deny correlation of the Rbr subzone with the M2 anomaly, or that of the RNbr subzone with M1 and M1n chrons (Fig. 3).

The Aptian Stage

In all the examined sections from the Caucasus,

Kopetdag and Volga Region, the lowermost of the Aptian are distinguished for a reverse polarity magnetozone, most probably analogous to the MO chron of the anomaly scale (Harland *et al.* 1982) (Fig. 3).

CONCLUSION

Comparisons of the regional and global data on the Berriasian-lower Aptian have shown the results obtained to accord in principle with the magnetostratigraphic materials known. The results allow to have more precise ideas of the Neocomian part of the palaeomagnetic scale.

In the stratigraphic aspect, the magnetozones recognised are reliable stratigraphic bench marks for synchronous correlations of the deposits, both on the regional and global scales.

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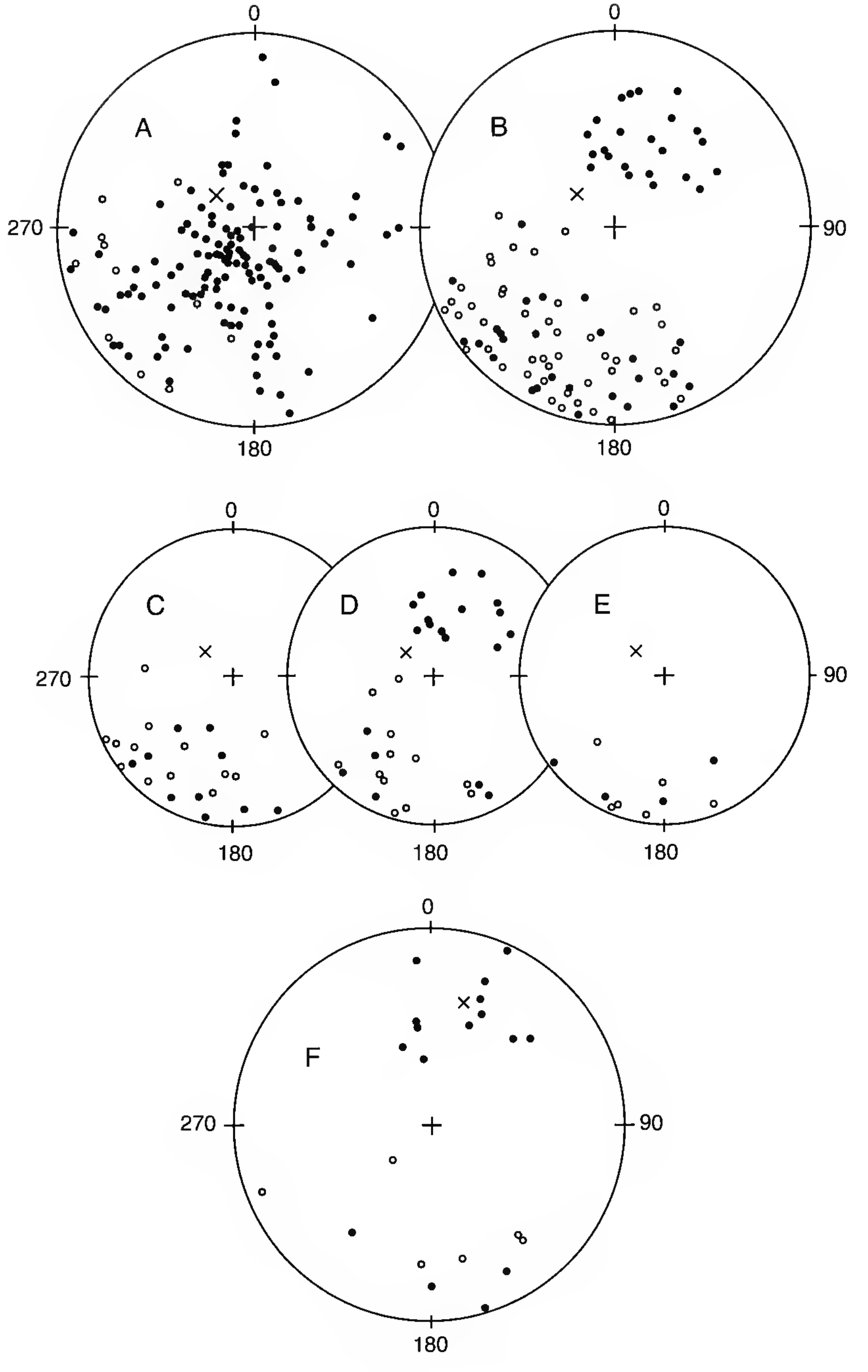
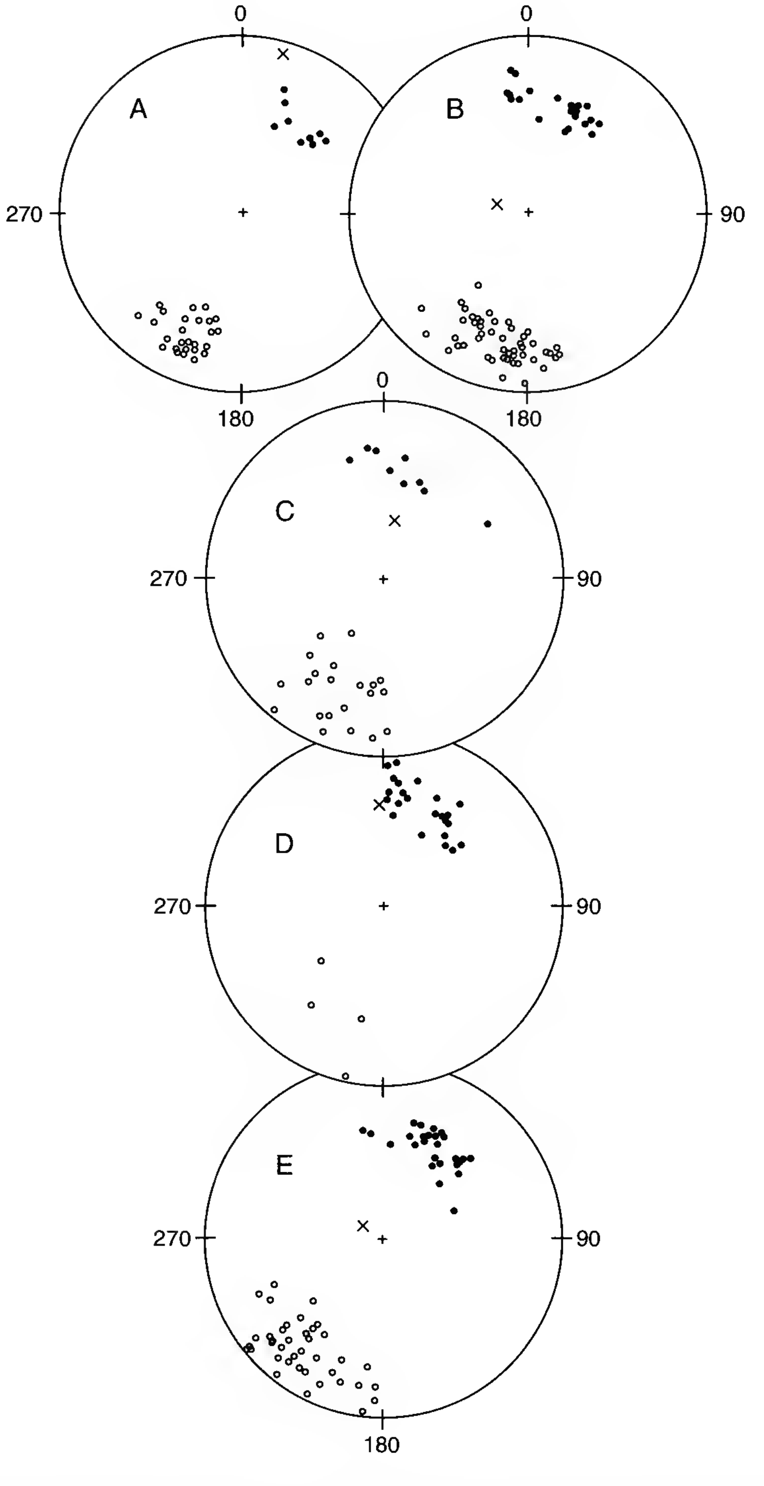
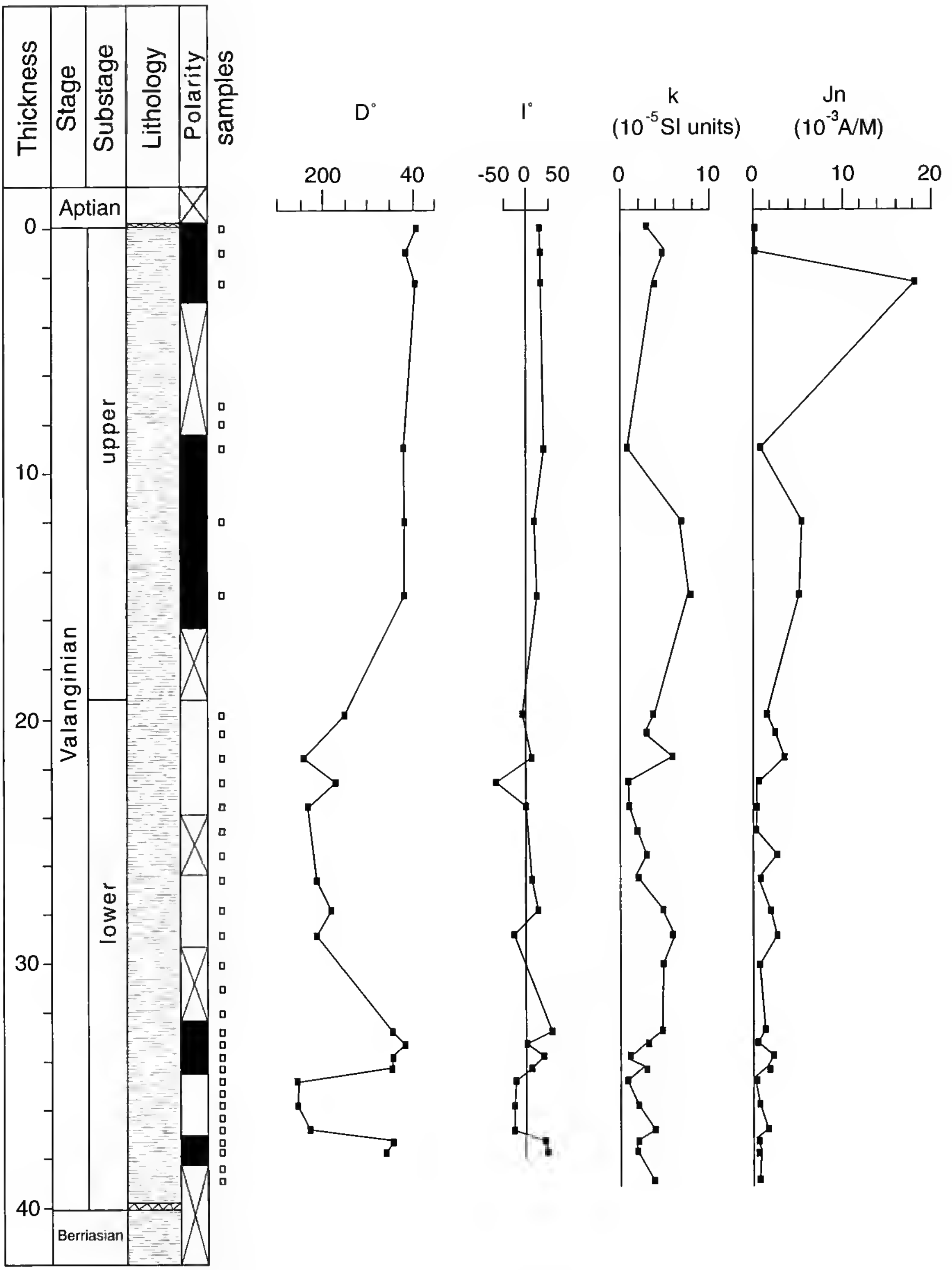
APPENDIX



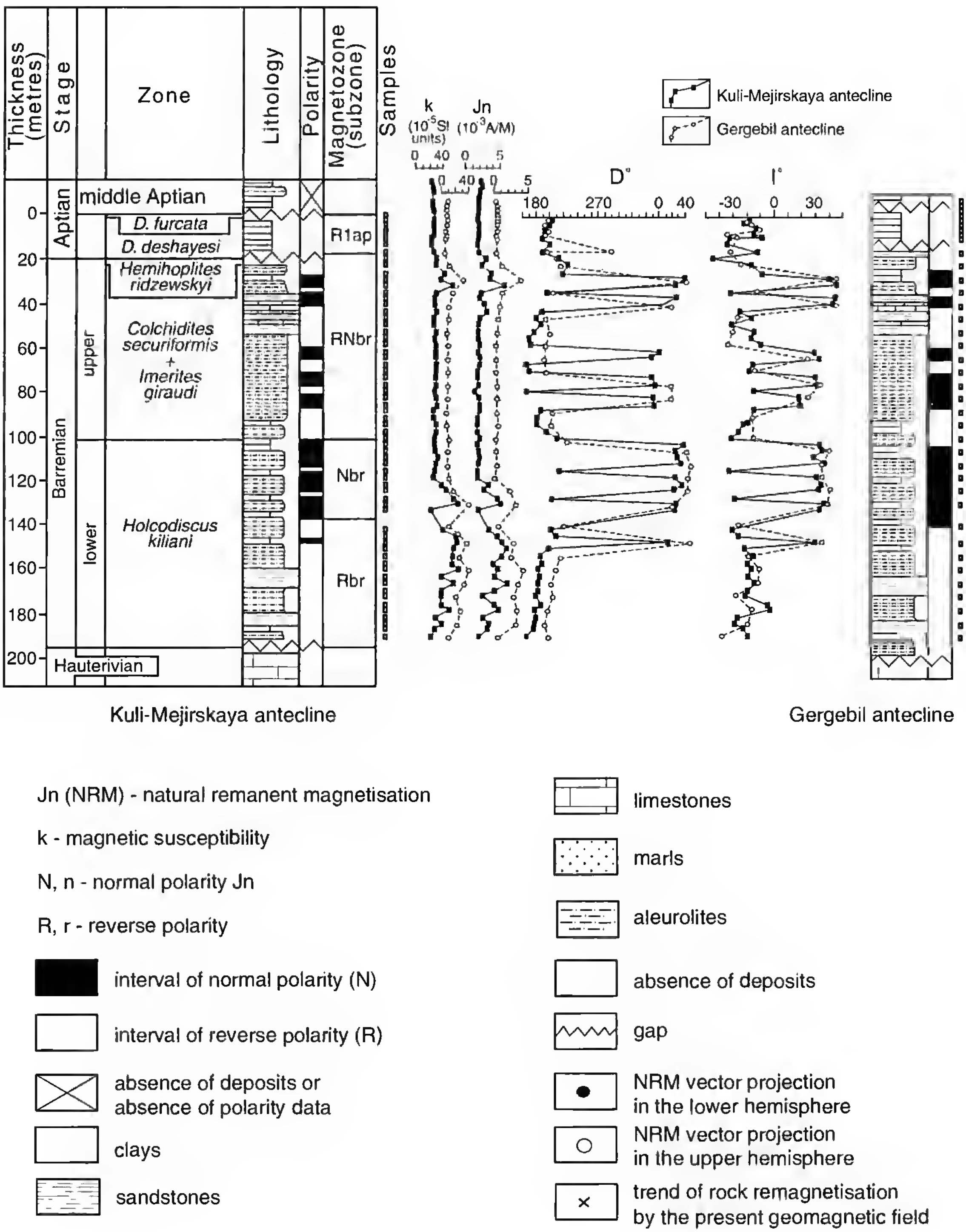
APPENDIX 1. — Stereographic projections of NRM vector. **A**-**E**, the Segiz-Yab River Section: **A**, **B**, the Barremian-lower Aptian deposits (A, after *in situ* measurements); **C**-**E**, magnetozones: **C**, Rbr; **D**, NRbr; **E**, R1ap; **F**, the Valanginian deposits from Tyuyesu Mountains.



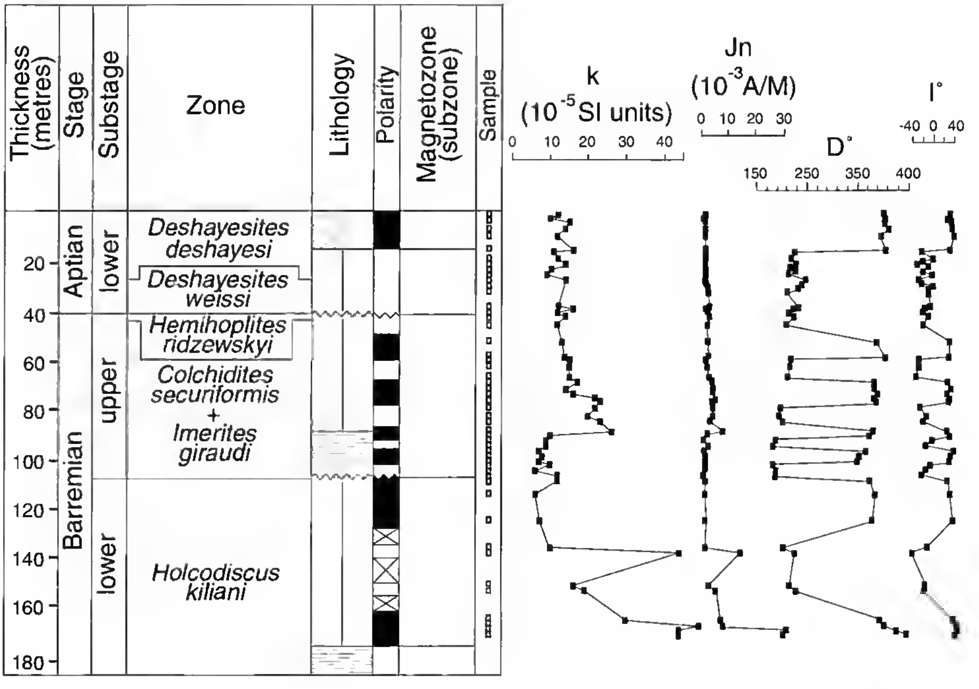
APPENDIX 2. — Stereographic projections of NRM vector. The Barremian-lower Aptian deposits: **A**, Gergebil Section (Gergebil anticline); **B**, Gergebil Section (Kuli-Mejirskaja anticline); **C**, Kislovodsk Section; **D**, the Urukh River Section; **E**, Akusha Section.



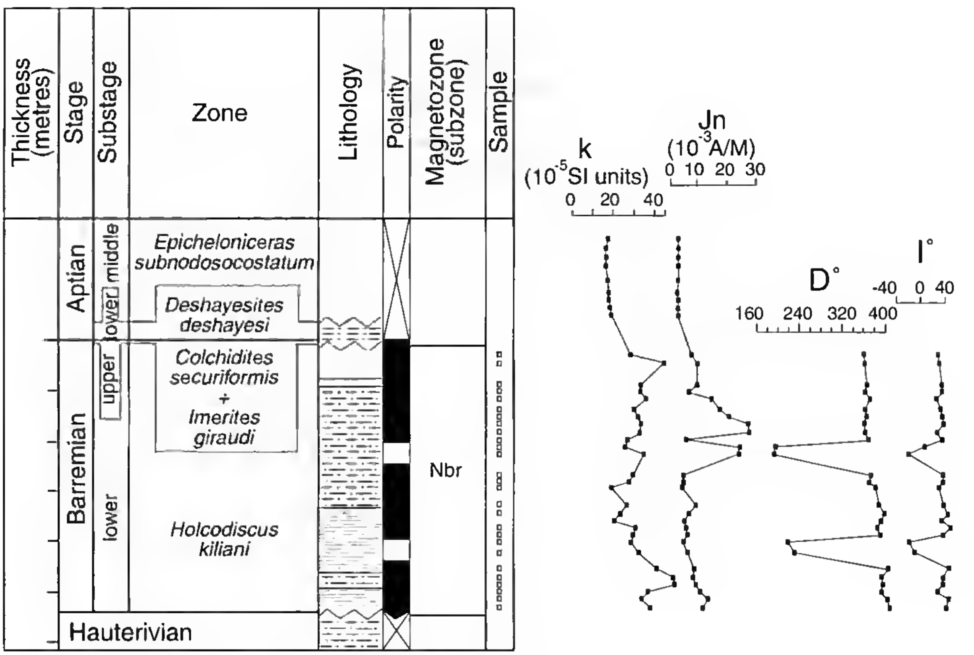
APPENDIX 3. — Palaeo- and petromagnetic characteristics of the Valanginian deposits from Tyuyesu Mountains. Same legend as Appendix 4.



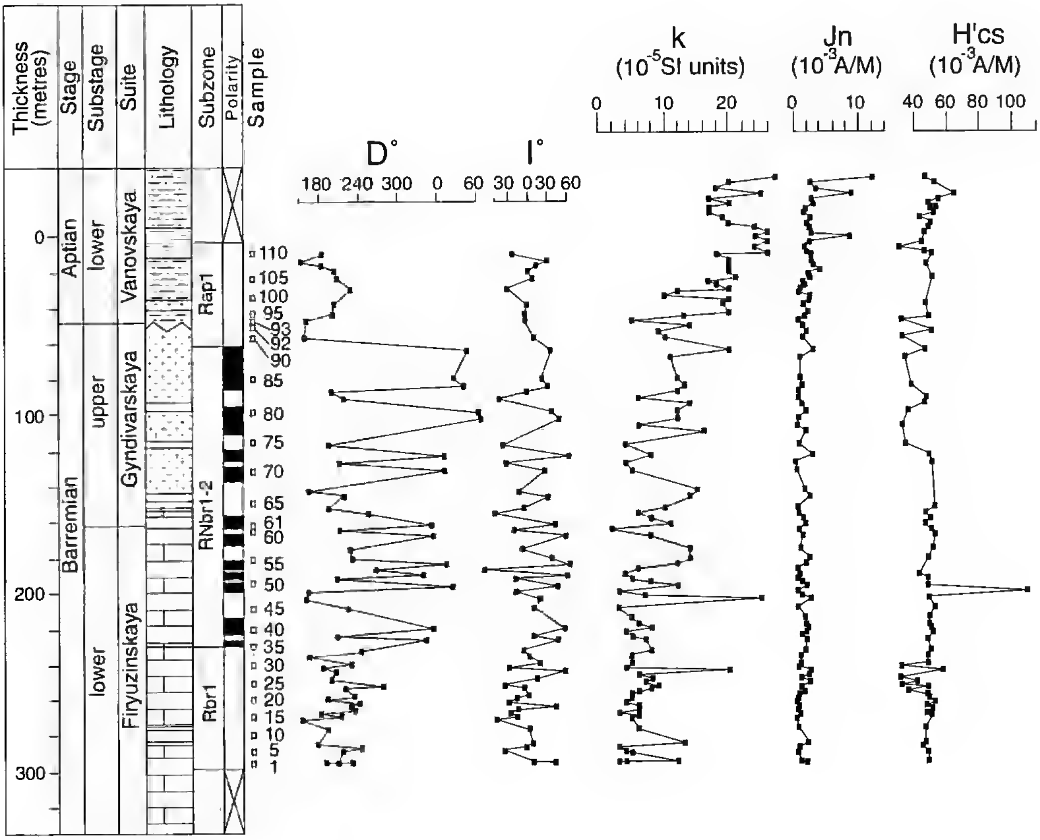
APPENDIX 4. — Palaeo- and petromagnetic characteristics of the Barremian-lower Aptian deposits from Gergebil Village.



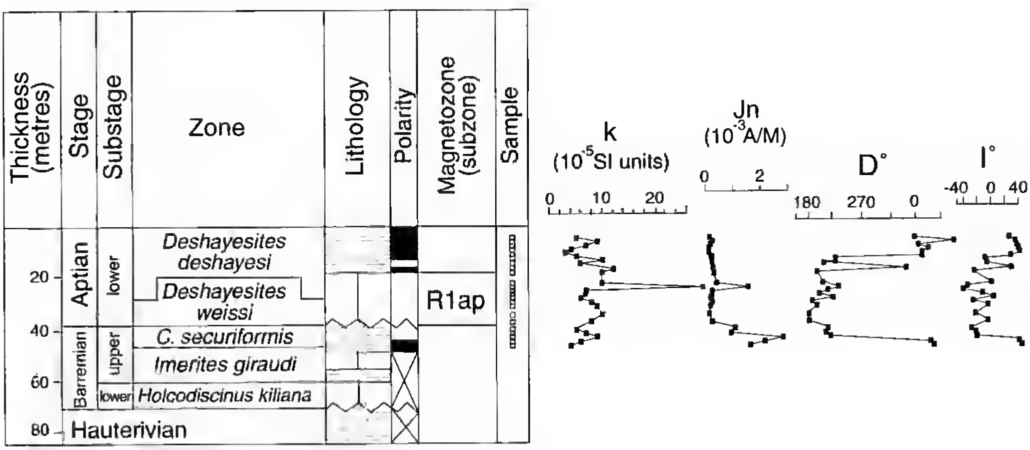
Appendix 5. — Palaeo- and petromagnetic characteristics of the Barremian-lower Aptian deposits from Akusha Village. Same legend as Appendix 4.



Appendix 6. — Palaeo- and petromagnetic characteristics of the Barremian deposits from the Urukh River. Same legend as Appendix 4.



APPENDIX 7. — Palaeo- and petromagnetic characteristics of the Barremian-lower Aptian deposits from the Segiz-Yab River. Same legend as Appendix 4.



APPENDIX 8. — Palaeo- and petromagnetic characteristics of the lower Aptian deposits from the Kislovodsk city. Same legend as Appendix 4.

Cretaceous sedimentary units of Mangyshlak Peninsula (western Kazakhstan)

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ABSTRACT
The Cretaceous succession of the Mangyshlak Region is reviewed. Two periods in the geological history of this region are recognised. Sedimentary units are determined for period on the base of detailed stratigraphy. Usually the units are separated by unconformities, differing in range and significance. The time of terrigenous sedimentation extends from the earliest Cretaceous to the early Turonian. The Neocomian succession was formed under changing Tethyan/Boreal influence. The main interruption in marine sedimentation took place in the early Hauterivian (which is probably missing in the region)-Barremian interval, during which continental sediments were deposited. Aptian to early Turonian deposits were formed within the European Palaeobiogeographical Region with a few Boreal invasions. The time of carbonate sedimentation in the "Chalk sea" Basin of the European Palaeobiogeographic Region began in the late Turonian and continued through the Maastrichtian.

KEY WORDS
Mangyshlak,
Kazakhstan,
Cretaceous,
stratigraphy,
unconformity,
palaeobiogeography.

RÉSUMÉ

Les unités sédimentaires crétacées de la péninsule du Mangyshlak (Kazakhstan occidental).

La série crétacée de la région du Mangyshlak est revue. Deux périodes dans l'histoire géologique de cette région sont reconnues. Les unités sédimentaires sont déterminées sur la base d'une stratigraphie détaillée. Habituellement, les unités sont séparées par des discordances, d'âge et de signification différents. La sédimentation terrigène s'étend du Crétacé basal au Turonien inférieur. La succession du Néocomien s'est formée sous le changement d'influence boréale-téthysienne. La principale interruption dans la sédimentation marine a lieu dans l'intervalle de l'Hauterivien inférieur (qui manque probablement dans la région)-Barrémien, durant lequel se déposent des sédiments continentaux. Les dépôts de l'Albien-Turonien inférieur se sont formés dans la province paléobiogéographique européenne avec quelques invasions boréales. La sédimentation carbonatée du bassin de la « Mer de la craie » du bassin paléobiogéographique européen débute au Turonien supérieur et se poursuit pendant le Maastrichtien.

MOTS CLÉS
Mangyshlak, Kazakhstan, Crétacé, stratigraphie, discordance, paléobiogéographie.

INTRODUCTION

This report includes biostratigraphic data concerning Cretaceous high resolution stratigraphy of the Mangyshlak Mountains (Fig. 1). The data were collected during their field trips by Naidin, Beniamovskii and Kopaevich (1980-1986), and by Baraboshkin (1989-1995). They were implemented by data from the geological literature.

The stratigraphic data are based or correlated with the standard biostratigraphical scheme for western "Boreal" Europe, taken from recent publications (Carter & Hart 1977; Robaszynski *et al.* 1982; Birkelund *et al.* 1984; Wood *et al.* 1984; Robaszynski 1987; Schoenfeld 1990; Rawson *et al.* 1996). We are not discussing details and problems of these stratigraphic correlations, which fall outside the scope of the present report.

STAGE BOUNDARIES

Investigation of palaeogeography and sequence/event stratigraphy must be based on a precise and reliable zonal stratigraphical scheme with preferably a wide correlation potential. For their investigations, the previous Russian authors have used the standard zonal scale for the Lower Cretaceous (Luppov *et al.* 1976, 1983, 1988; Saveliev 1992; Baraboshkin 1992, 1996, 1997) and for the Upper Cretaceous the stratigraphical scheme of the Mangyshlak, where the foraminifera zonal scheme is closely correlated with zonal schemes based on macrofauna (Naidin *et al.* 1984a, b, 1995).

Lower Cretaceous

The Lower Cretaceous of Mangyshlak is characterised by a terrigenous deposition in shallow water to near-shore and continental environments. The stratigraphy of the Lower Cretaceous of Mangyshlak is based mainly on ammonite distribution (Fig. 2). It was mainly developed by Semenov, Luppov, Sokolov, Saveliev, Bogdanova. The biostratigraphic scale based on bivalves is particularly useful and was developed by Mordvilko, Nikitina, Saveliev, Bogdanova. The foraminifera scale results from research by Myatlyuk and Vasilenko. Application of a foraminifera scale is limited for the Neocomian because of strong facies control, but is very useful for the Aptian-Albian interval.

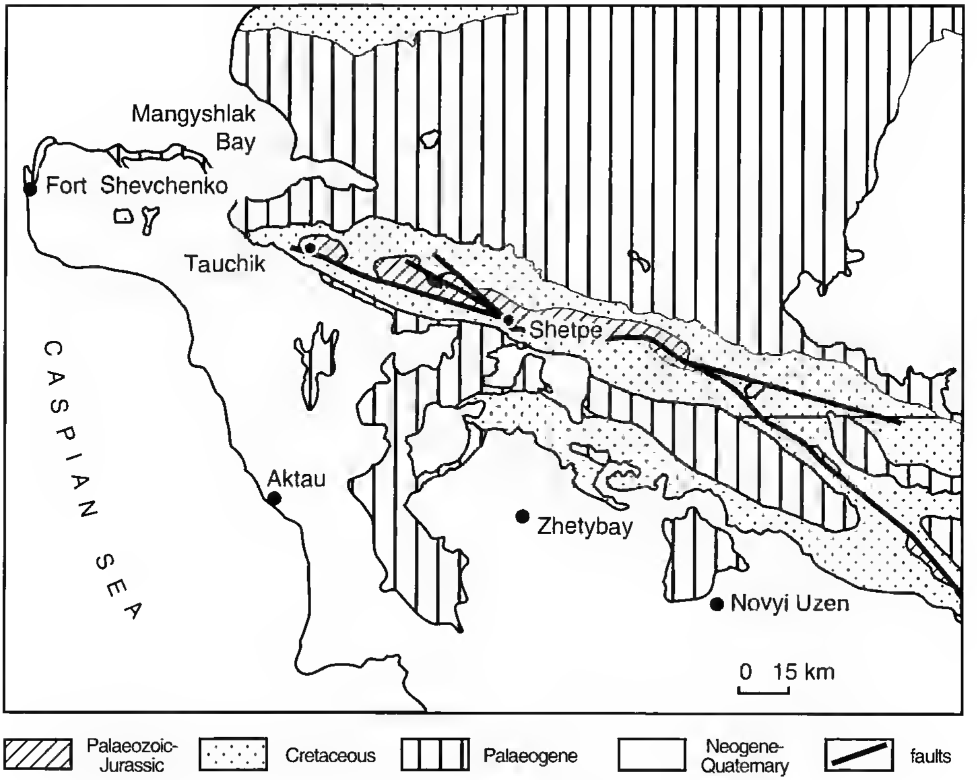

FIG. 1. — Geological map of Mangyshlak.

The Jurassic/Cretaceous boundary coincides with a major unconformity. Berriasian sediments are represented by a shallow water sandy-silty succession, with marl and limestone intercalations, and oyster banks. The sediments are irregularly distributed because of later erosion. The Jurassic/Cretaceous boundary in Mangyshlak is determined by the appearance of ammonites of the Tethyan family Berriasellidae: *Riasanites* Spath, *Neocosmoceras* Blanchet, *Subalpinites* Mazenot, etc. and of some representatives of the Boreal family Craspeditidae: *Surites* Sasonov (Luppov *et al.* 1988). The benthic assemblage also contains a mixture of Boreal and Tethyan bivalves, gastropods, brachiopods and other fauna: *Buchia volgensis* (Lahusen), *B. okensis* (Pavlow), *B. uncitoides* (Pavlow) (Boreal); *Myophorella loewinson-lessingi* (Renngarten), *Rutitrigonia laevuscula* (Lycett) (Tethyan) and others. It is interesting, that foraminifera data demonstrate the absence of Boreal elements (Luppov *et al.* 1988). The fauna indicates the presence of the upper Berriasian only and the absence of the Volgian to middle Berriasian interval. The faunal assemblage suggests that marine conditions disappeared near the Jurassic/Cretaceous boundary and after a short Tethyan transgression, Boreal water penetrated in the area.

The base of the Valanginian is marked by an erosional unconformity and by the presence of phosphoritic conglomerates. It was recognised by the appearance of Boreal Valanginian ammonites and buchiids. Valanginian sediments were formed in shallow water environments. They are represented by various terrigenous facies with intercalations of carbonates. The Valanginian is characterised by the development of a Boreal ammonite fauna: *Nikitinoceras* Sokolov, *Polyptychites* Pavlow, *Dichotomites* v. Koenen (Luppov *et al.* 1983). There is the only evidence for the presence of Tethyan fauna is the upper Valanginian ammonite *Neohoploceras* sp., figured

STAGE	SUBSTAGE	MEDITERRANEAN SCALE (Hoedemaeker et al. 1995, simplified) ZONE, SUBZONE		MANGYSHLAK (Saveliev et al. 1963; Saveliev 1992; Luppov et al. 1983, 1988; with changes by Baraboshkin, this paper) ZONE, SUBZONE
ALBIAN	UPPER	*Stoliczkaia dispar*	*Stoliczkaia (S.) dispar*	*Pleurohoplites studeri*
			S. (F.) blancheti	*Callihoplites vraconensis*
		Mortoniceras inflatum		*Mortoniceras (Mortoniceras) inflatum*
				Semenovites (Semenovites) michalskii
				Semenovites (Planihoplites) pseudocoelonodus
				Semenovites (Semenovites) tamalakensis
	MIDDLE	*Euhoplites lautus*		*Anahoplites rossicus*
				Hoplites (H.) perarmatus
		Euhoplites loricatus		*Daghestanites daghestanensis**
				Anahoplites intermedius
		Hoplites dentatus	*Hoplites spathi*	*Hoplites (H.) spathi*
			Lyelliceras lyelli	*Lyelliceras (L.) lyelli*
		Douvilleiceras mammillatum		*Pseudosonneratia (Isohoplites) eodentata**
	LOWER			*Otohoplites crassus*
				Protohoplites (H.) puzosianus
				Sonneratia (Eosonneratia) caperata
				Sonneratia (Eosonneratia) rotula
				*Sokolovites subdragunovi**
				Sonneratia (Eosonneratia) solida
				Sonneratia (Globosonneratia) perinflata
		Leymeriella tardefurcata		Beds with *Leymeriella (Neoleymeriella)**
				Anadesmoceras strangulatum
				*Leymeriella (Leymeriella) acuticostata**
				*Arcthoplites (Subarcthoplites) probus**
				Arcthoplites (Arcthoplites) jachromensis
				*Leymeriella (Leymeriella) rudicostata**
APTIAN	UPP.	*Hypacanthoplites jacobi*		MISSING
		Acanthohoplites nolani		*Nolaniceras nolani*
				Acanthohoplites aschiltaensis
	MID.	*Parahoplites melchioris*		*Parahoplites melchioris*
		Epicheloniceras subnodosocostatum		*Epicheloniceras subnodosocostatum*
	LOWER	*Dufrenoya furcata*		*Dufrenoya furcata*
		Deshayesites deshayesi		*Deshayesites deshayesi*
		Deshayesites weissi		*Deshayesites weissi*
		Deshayesites tuarkyricus		
BARREMIAN				CONTINENTAL FACIES
HAUTERIV.	UPP.			?
	LOW.			MISSING
VALNGINIAN	UPPER	*Neocomites (Teschenites) pachydicranus*		*Dichotomites bidichotomus*
		Saynoceras verrucosum		
	LOWER	*Busnardoites campylotoxus*		*Polyptychites polyptychus*
		Thurmanniceras pertransiens		*Nikitinoceras hoplitoides**
		Thurmanniceras otopeta		
BERRIASIAN	UPPER	*Fauriella boissieri*		*Riasanites rjasanensis**
				"*Euthymiceras sp.*"*
				*Transcaspiites transfigurabilis**
	MIDD.	*Tirnovella occitanica*		MISSING
	LOW.	*Berriasella jacobi*		

FIG. 2. — Ammonite zonation of Lower Cretaceous of Mangyshlak. Stars mark ammonite zones, revised or proposed for the first time in this paper.

from Mangyshlak by Gordeev (1971). The benthic assemblage is mixed and contains both Boreal and Tethyan elements, bivalves: *Buchia keyserlingi* (Lahusen), *B. sibirica* (D. N. Sokolov) (Boreal), *Iotrigonia scapha* (Agassiz), *Litschkovitrigonia tenuituberculata* Saveliev; corals: *Thamnasteria digitata* Fromentel, *Stereocoenia collinaria* (Fromentel) (Tethyan).

The Valanginian/Hauterivian boundary is very difficult to recognise in Mangyshlak, and in the whole Peri-Caspian Region. The lower Hauterivian was traditionally described from Mangyshlak according to Saveliev. He cited records of *Dichotomites bidichotomus* (Leymerie) (Saveliev 1958; Saveliev & Vasilenko 1963). According to up-to-date interpretation, this ammonite should be referred to the upper Valanginian of mainly Boreal Province. Luppov *et al.* (1983) referred shell-rich beds and sandstones to the Hauterivian on the base of the presents of the brachiopods *Cyclothyris irregularis* (Pictet), *C. gillieroni* (Pictet) and of the corals *Actinostrea colliculosa* Trautschold (in East Karatau). The only record of the lower Hauterivian *Lyticoceras* sp. is from the Peri-Caspian Region (Koltypin 1970). We assume that this identification was a erroneous, because the inadequate understanding of *Lyticoceras* Hyatt, 1900 in the stratigraphic literature of that time. If this were the case then there is no real evidence for the existence of lower Hauterivian sediments in that area. The other reason for the absence of lower Hauterivian in Mangyshlak is the general palaeogeography. Sediments of that age are missing over most of the Russian Platform (in the north), in the northern part of the Scythian Platform (to the west); in Kazakhstan and Turkmenia (to the south-east) they are present mainly in continental facies. In the Tuarkyr area (situated between the Great Balkhan and Mangyshlak) the lower Hauterivian is also missing. This is supported mainly by ostracod data (Alekseeva *et al.* 1972).

The presence of upper Hauterivian in Mangyshlak is can be discussed, but is more plausible, because sediments of that age cover the eastern part of the Russian Platform (including the Peri-Caspian) and the Scythian Platform. It is possible that part of the continental red-coloured unit (Barremian, according to traditional stratigraphy) belongs to the upper Hauterivian as was supposed by Saveliev & Vasilenko (1963).

The Hauterivian/Barremian boundary is not characterised by ammonites in Mangyshlak. Usually in the Peri-Caspian area the boundary is placed at the disappearance of the upper Hauterivian Boreal ammonites *Simbirskites* Pavlow and *Craspedodiscus* Spath and the appearance of the belemnite *Oxyteuthis* Stolley. The Barremian age of red- and rainbow-coloured sands, silts and clays (Kugusem Formation) is supported by a specific foraminiferal assemblage; *Gyroidinoides sokolovae* Mjatliuk and *Conorbinopsis barremicus* (Mjatliuk) by comparison with Peri-Caspian sections (Myatlyuk 1980) and by ostracod data (Korotkov & Shilova 1982). Sediments of that type are widely distributed in the Turanian Platform area. It was the time of separation from the Russian Platform Basin caused by sea-level fall and followed by the freshening of the water.

The Barremian/Aptian boundary is recognised more easily in the region by the appearance of the lower Aptian ammonite *Deshayesites* Kasansky. The base of the Aptian coincides with a regional transgressive surface and condensed beds with *Deshayesites deshayesi* (Leymerie *in* d'Orbigny), *D. dechyi* (Papp), *Tropaeum* sp. and other northern Tethyan faunal elements (Saveliev & Vasilenko 1963). The Aptian succession is represented by a sandstone-siltstone shallow marine unit with clays at the base, containing numerous small unconformities. The three Aptian substages are presented in this area, but the upper Aptian succession is condensed in the basal phosphoric horizon of the lower Albian. The ammonite assemblage known from Mangyshlak (*Deshayesites* Kasansky, *Parahoplites* Anthula, *Epicheloniceras* Casey, *Acanthohoplites* Sinzow) demonstrates the influence of northern Tethyan water.

The Aptian/Albian boundary is defined at the base of *Leymeriella tardefurcata* zone, which is widely distributed in the region. The Albian succession is formed by shallow-marine and near-shore terrigenous deposits. It was investigated in detail (Saveliev 1973, 1992). Records of *Arcthoplites jachromensis* (Nikitin) together with

leymeriellids (Saveliev 1973) are very important for characterising the short-term influence of Boreal seas and this taxon is a good for correlating Arctic and Tethyan scales (Baraboshkin 1992, 1996). The faunal assemblage is very rich in ammonites and contains mainly European forms (*Leymeriella* Spath, *Sonneratia* Bayle, *Otohoplites* Steinmann, *Hoplites* Neumayr, *Callihoplites* Spath, etc.). The Tethyan influence is clearly visible in the lower Albian (*Douvilleiceras* Grossouvre abundance), lower middle Albian (appearance of rare *Lyelliceras*) and from the middle upper Albian onwards (where *Mortoniceras* Meek, *Stoliczkaia* Neumayr and heteromorphs occur frequently). At the same time, an endemic evolution took place (the lower upper Albian, when *Semenovites* Glasunova was widely distributed). The faunal distribution indicates a relative sea separation. The Albian succession is very complete in terms of ammonite stratigraphy (Saveliev 1992), but contains numerous small stratigraphical gaps, marked usually by phosphorites. The style of deposition during the Albian changed from shallow open marine in the beginning to near-shore in the end typical for Peri-Caspian (Baraboshkin 1996, 1997). The top of the Albian is regionally eroded and some of the Albian ammonites are found reworked, in condensed basal phosphoritic horizon of lower Cenomanian.

Upper Cretaceous

The Cenomanian/Turonian boundary is at the top of the *Sciponoceras gracile* zone. The belemnite *Praeactinocamax plenus* (Blainville) is also characteristic for the terminal part of the Cenomanian. The lower Turonian boundary position practically corresponds to appearance of the *Mytiloides* inoceramid lineage and this level is an event which can be traced throughout the Tethyan and Boreal realms.

The Turonian/Coniacian boundary coincides with the first appearance of *Cremnoceramus rotundatus* (*sensu* Tröger *non* Fiege: Kauffman *et al.* 1996). This level is lower than the firsr *Cremnoceramus deformis* (Meek), which was mentioned in previous Russian schemes.

The Coniacian/Santonian boundary coincides with the base of the *Cladoceramus undulatoplicatus* zone. It is a very good level, because the remains of this taxon is very easily identified.

The Santonian/Campanian boundary is at the base of the *Gonioteuthis granulata quadrata* zone in western "Boreal" Europe. This level coincides almost exactly with the disappearance of *Marsupites testudinarius* (Schlotheim) in Mangyshlak as elsewhere. Zonal species of belemnites not been found here. *Gonioteuthis* Bayle species do not extent to the east beyond the Donets Basin. Assemblages of other belemnites, *Actinocamax laevigatus* Arkhangelsky, determine the age of this interval as early Campanian (Naidin *et al.* 1984b).

The Campanian/Maastrichtian boundary is very sharp: mass findings of *Belemnitella langei* Jeletzky group are suddenly replaced by mass findings of *Belemnella*.

The Maastrichtian/Danian boundary is very sharp also, because a stratigraphical gap is present and shown by the disappearance of many macrofaunal groups: ammonites, belemnites, inoceramids.

The micropalaeontological scheme for the Upper Cretaceous of Mangyshlak is very detailed and contains 26 foraminiferal subdivisions (Fig. 3). The identification of zones is based on tracing species assemblages. At different time intervals the representatives of different genera took a leading stratigraphic significance: *Gavelinella* Brotzen for the Cenomanian/Turonian, *Stensioeina* Brotzen for the Coniacian-Santonian, *Bolivinoides* Cushman for the Campanian/Maastrichtian.

The common occurrences of *Gavelinella cenomanica* (Brotzen) and *Rotalipora appeninnica* (Renz) are referred to the lower Cenomanian, and appearance of *Lingologavelinella globosa* (Brotzen) is related to the middle-upper Cenomanian.

The lower Turonian interval of foraminifera evolution is marked by the presence of large *Hedbergella* Broennimann & Brown and *Whiteinella* Pessagno (zone à « Grandes Globigerines »), while the middle-upper Turonian interval is determined by appearance and evolution of *Marginotruncana* sp. and *Gavelinella moniliformis* (Reuss).

The abundance of *Marginotruncana* Hofker or "Grandes Rosalines" increases near the Turonian-

Coniacian boundary deposits. This boundary is determined by the mass appearance of *Gavelinella praeinfrasantonica* (Mjatliuk) (= *G.* aff. *vombensis*), *Reussella kelleri* Vassilenko and also by small *Stensioeina*. Mass occurrence of typical *Stensioeina granulata granulata* (Olbertz), *Gavelinella thalmanni* (Brotzen), *G. vombensis* (Brotzen) (= *G. infrasantonica*), *Osangularia whitei whitei* (Brotzen) are a typical for the upper Coniacian. *Stensioeina exculpta exculpta* (Reuss) appears in the terminal part of the Coniacian and is especially numerous in the lower Santonian.

The Santonian/Campanian boundary is considered to be within the *Bolivinoides strigillatus* zone. The appearance and mass occurrence of *Stensioeina pommerana* Brotzen, *Gavelinella clementiana clementiana* (d'Orbigny), *Bolivinoides decoratus* (Jones) are typical for the lower Campanian, those of *Brotzenella monterelensis* (Marie) for the middle Campanian. The upper Campanian is determined by the appearance of *Cibicidoides voltzianus* (d'Orbigny) followed by *Bolivinoides draco miliaris* Hiltermann & Koch, *Bolivina kalinini* (Vassilenko) (= *B. incrassata* (Reuss), narrow specimens), upwards by *Brotzenella taylorensis* (Carsey) and in the most terminal part by *Angulogavelinella gracilis* (Marsson).

The Campanian/Maastrichtian boundary is determined on the basis of the appearance of *Neoflabellina reticulata* (Reuss) and *Bolivina decurrens* (Ehrenberg), but also on the presence of abundant *Angulogavelinella gracilis* (Marsson). The middle part of the lower Maastrichtian is differentiated by *Brotzenella complanata* (Reuss) and the upper part by *Bolivinoides draco draco* (Marsson) and *Anomalinoides subcarinatus* (Cushman & Deaderick). The upper Maastrichtian is characterised by the appearance of *Brotzenella praeacuta* (Vassilenko) and of *Anomalinoides pinguis* (Jennigs) and in its terminal part by the of occurrence of *Hanzawia ekblomi* (Brotzen) and of *Pseudotextularia elegans* (Rzehak).

This stratigraphical scheme allows correlation of all Upper Cretaceous sections in Mangyshlak with those of many areas of western part of "Boreal" Europe: Anglo-Paris Basin, western Germany and lowland part of Poland.

THE SUCCESSION OF SEDIMENTARY UNITS

"Sedimentary units" stand for relatively conformable succession of genetically related strata bounded at the top and base by unconformities or by correlative conformities. This is a modification of an earlier usage by Sloss (1976). There are many different visible and invisible gaps and unconformities in the investigated area (Saveliev 1971; Naidin 1987; Naidin & Kopaevich 1988).

Lower Cretaceous sedimentary units

The Lower Cretaceous succession contains many different stratigraphical gaps and several large unconformities. Mostly they are erosional in origin because of shallow conditions of the whole succession. The main gaps and flooding surfaces, which separate different sedimentary units, could be determined in the following levels (Fig. 3).

The lower Berriasian: a gap appeared during significant palaeogeographical rebuilding and interrupting of sedimentation. Hence, an unconformity is visible at the base of the upper Berriasian (it overlies different parts of the Mesozoic or Palaeozoic sequence). There are many small gaps inside the Berriasian interval which are only of local significance.

The gap and unconformity between the upper Berriasian and lower Valanginian extend over 1-2 ammonite zones. Usually, this level is marked by erosional surface with phosphorites. Also typical for Mangyshlak is that the lower Valanginian overlays the Middle Jurassic, and highly condensed phosphoric horizons were deposited. The highest condensation is seen in the *Nikitinoceras hoplitoides* zone, but the base of the Valanginian (an analogue of the *Neotollia klimovskiensis* zone of Siberia) is missing.

In the Valanginian-Barremian interval a hiatus includes the complete lower Hauterivian. The gap is usually indicated by a thin basal level with phosphorites, softground and an erosional surface development. The existence and completeness of other parts of the Hauterivian/Barremian succession is under discussion and needs additional palaeontological evidence.

The Barremian/Aptian boundary hiatus extends over 1-3 ammonite zones. It is tepresented by a

Symbol	Zone	
m_2	***Hanzawaia ekblomi***, *Anomalinoides pinguis, Gavelinella* ex gr. *danica, Pseudotextularia varians, P. elegans*	XXVI
m_1^3-m_2	***Brotzenella praeacuta***, *Cibicides kurganicus, Gavelinella pertusa, Tappanina selmensis*	XXV
m_1^3	***Bolivinoides draco draco***, *Coleites crispus, Gavelinella midwayensis, Stensioeina caucasica*	XXIV
m_1^2	***Brotzenella complanata***, *Spiroplectammina suturalis, Gavelinella welleri, Anomalinoides subcarinatus, Bolivina incrassata incrassata, B. incrassata crassa*	XXIII
cp_3^3-$m_1^?$	***Angulogavelinella gracilis stellaria***, *Neoflabellina reticulata, Osangularia navarroana, Gyroidina globosa, Cibicidoides bembix, Bolivina decurens, Bolivinoides delicatulus, B. peterssoni, Reussella minuta*	XXII
cp_3^3	***Brotzenella taylorensis***, *Neoflabellina praereticulata, Bolivina incrassata incrassata, Pseudouvigerina cristata, Bolivinoides giganteus*	XXI
cp_3^2	***Bolivinoides draco miliaris***, *Eponides frankei, E. conspectus, Gavelinella cayexi mangyshlakensis, Bolivina kalinini, Gemellides orcinus, Rugoglobigerina rugosa*	XX
cp_3^1	***Cibicidoides voltzianus***, *Heterostomella foveolata, Plectina ruthenica, Globoratalites emdyensis, Gavelinella clementiana laevigata, Globotruncana morozovae*	XIX
cp_2	***Brotzenella monterelensis***, *B. menneri, Gavelinella clementiana usakensis, Arenobulimina convexocamerata, Heterostomella praefoveolata, Orbignyna sacheri, O. ovata, Voloshinovella tertia, V. laffitei*	XVIII
cp_1^3(up)	***Cibicidoides aktulagayensis***, *Plectina convergens*	XVII
cp_1^3(low)	***Cibicidoides temirensis***, *C. montanus, Eponides biconvexus, Bolivinoides laevigatus laevigatus, Bolivinitella galeata*	XVI
cp_1^2 cp_1^1	***Bolivinoides decoratus decoratus***, *B. granulatus, Osangularia cordieriana, Globigerinelloides volutus* ***Gavelinella clementiana clementiana***, *G. dainae, Neoflabellina rugosa, Stensioeina pommerana, Reussella pseudospinulosa, Bolivinoides laevigatus finitima, Globotruncana arca*	XV XIV
st_2-cp_1^1	***Bolivinoides strigillatus***, *Ataxophragmium orbignynaeformis, Gavelinella stelligera, Globotruncana arcaformis*	XIII
st_2	***Osangularia whitei polycamerata***, *O. whitei crassa, O. whitei whitei, Gavelinella* ex gr. *stelligera, Cibicides excavatus*	XII
st_1	***Stensioeina granulata perfecta***, *S. granulata incondita, S. exsculpta gracilis*	XI
cn_2-st_1	***Stensioeina exsculpta exsculpta***, *Gavelinella vombensis, G. umbilicatula, Cibicidoides eriksdalensis*	X
cn_2	***Stensioeina granulata granulata***, *Spiroplectammina embaensis, Valvulineria laevis, Gyroidina turgida, Globorotalites michelinianus, Osangularia whitei whitei, Gavelinella vombensis* (= *G. infrasantonica*), *G. thalmanni, G. costulata, Bolivinita eleyi*	IX
cn_1	***Reussella kelleri***, *Gavelinella praeinfrasantonica, Gavelinella kelleri, G. costulata, Stensioeina granulata kelleri, Marginotruncana coronata*	VIII
t_3	***Ataxophragmium nautiloides***, *Gavelinella* ex gr. *costulata, Cibicidoides praeeriksdalensis, Marginotruncana renzi*	VII
t_2	***Gavelinella moniliformis***, *G. ammonoides, Spiroplectammina praelonga, Gaudryina variabilis, Globorotalites multiseptus, Reussella carinata, Marginotruncana lapparenti, M. marginata, Hedbergella agalarovae*	VI
t_1(up)	***Globorotalites hangensis***, *Spiroplectammina cuneata, Gaudryina subserrata, Gyroidina nitida, Valvulineria lenticula, Gavelinella vesca, Cibicidoides apprima*	V
t_1(low)	***Hedbergella holzli***, *H. portsdownensis, Whiteinella brittonensis, W. archeocretacea, W. baltica, Globigerinelloides bentonensis*	IV
$cm_{2\text{-}3}$	***Lingulogavelinella globosa***, *Brotzenella berthelini, Gavelinella vesca*	III
cm_1	***Gavelinalla cenomanica***, *G. baltica, Lingulogavelinella orbiculata, Cibicides polyrraphes polyrraphes, Neobulimina numerosa, Hedbergella caspia, Thalmanninella appenninica*	I- II

FIG. 3. — Foraminifera zonation of Upper Cretaceous of Mangyshlak.

condensed horizon containing small phosphatic pebbles with reworked lower Aptian fauna.

The Aptian/Albian boundary gap including the upper Aptian-basal lower Albian (2-3 ammonite zones to the whole middle-upper Aptian and basal Albian). It is an important unconformity marked by a strong erosional and environmental break. Traces of upper Aptian are recognisable in rewashed phosphatic pebbles in Mangyshlak sections.

There is an unconformity in the topmost Albian (usually less than one ammonite zone, but in some Mangyshlak sections – half of the stage is missing). A gap separates Lower and Upper Cretaceous sequences. It is easily recognisable by a thick phosphoritic horizon and by an unconformity at the base. All hiatuses are more extensive in easterly direction in the marginal parts of the basin. Because of the gaps mentioned above, the following sequences were recognised in the Lower Cretaceous of Mangyshlak.

Upper Berriasian-Valanginian unit (I): the unit is separated by a very strong unconformity at the base of the upper Berriasian and by an erosional surface at the top of the Valanginian. It is a very complex member with many small gaps, especially in the lower Valanginian part. This unit begins with coarse-grained near-shore sediments and finishes with relatively deep-water clayey sediments for the latest stage of sequence development. It is important that the unit was formed mainly under Boreal water influence with short-term penetration of Tethyan water at its beginning.

Upper Hauterivian (?)-Barremian unit (II): the unit includes mainly subaeral sediments. There is an erosional surface at the base of the sequence and another erosional surface at its top.

Aptian unit (III): the unit starts at the transgressive part of the lower Aptian with an erosional surface and an unconformity at its base. The upper limit of unit III is an erosional surface with the condensed upper part of the Aptian stage. This unit was formed during a transgressive-regressive cycle, finished during the late Aptian in near-shore to subaeral (partially) environments. The deepest conditions followed by an anoxic event existed during the latest early-middle Aptian. The deposition took place under Tethyan water influence.

Albian unit (IV) is characterised by a rapid transgression and a slow late early to latest Albian shallowing. It is separated by an erosional surface from the Aptian. At the top, there is a strong unconformity with erosional surface and phosphoric condensation overlain by the Cenomanian. Unit IV is represented by a transgressive-regressive cycle with a change of conditions at the end of the early Albian-beginning of the middle Albian. During this time, the sandy to silty-clayey shallow marine sedimentation changed into a near-shore environment. The Albian development of Mangyshlak Basin was affected by Boreal influence at the beginning, by separation from other basins in the early late Albian and by an increased influence of Tethyan waters in the latest Albian.

Upper Cretaceous sedimentary units

Six sedimentary units compose the succession of the Upper Cretaceous in Mangyshlak (Fig. 4). Units I-II are differentiated from those with terrigenous composition: sands, sandstones and clays. Units III-VI contain carbonate clays, marls and chalk. There are "black beds" on the Cenomanian/Turonian boundary in the stratigraphically complete sections.

There is only one regional unconformity in the Upper Cretaceous succession of Mangyshlak area: at the Cenomanian/Turonian boundary, but relatively complete sections also exist. Many small hiatuses similar to hard grounds are visible in the carbonate part of all sections of Mangyshlak (Naidin & Kopaevich 1988). The genesis of these hardgrounds is explained by a combined effect of climatic and eustatic agents. It is suggested that carbonate rocks containing hardgrounds are a modification of rhythmically bedded strata.

The clay intercalations or "clays" differ from the carbonate sediments above and below in the abrupt decrease in the $CaCO_3$ amount. It is assumed that the "clays" result from submarine early carbonate biogeochemical dissolution at the sea floor caused by an abrupt increase in biological productivity of the pelagic zone (Naidin & Kopaevich 1988).

The Upper Cretaceous interval in Mangyshlak can be divided in six units. These units and their

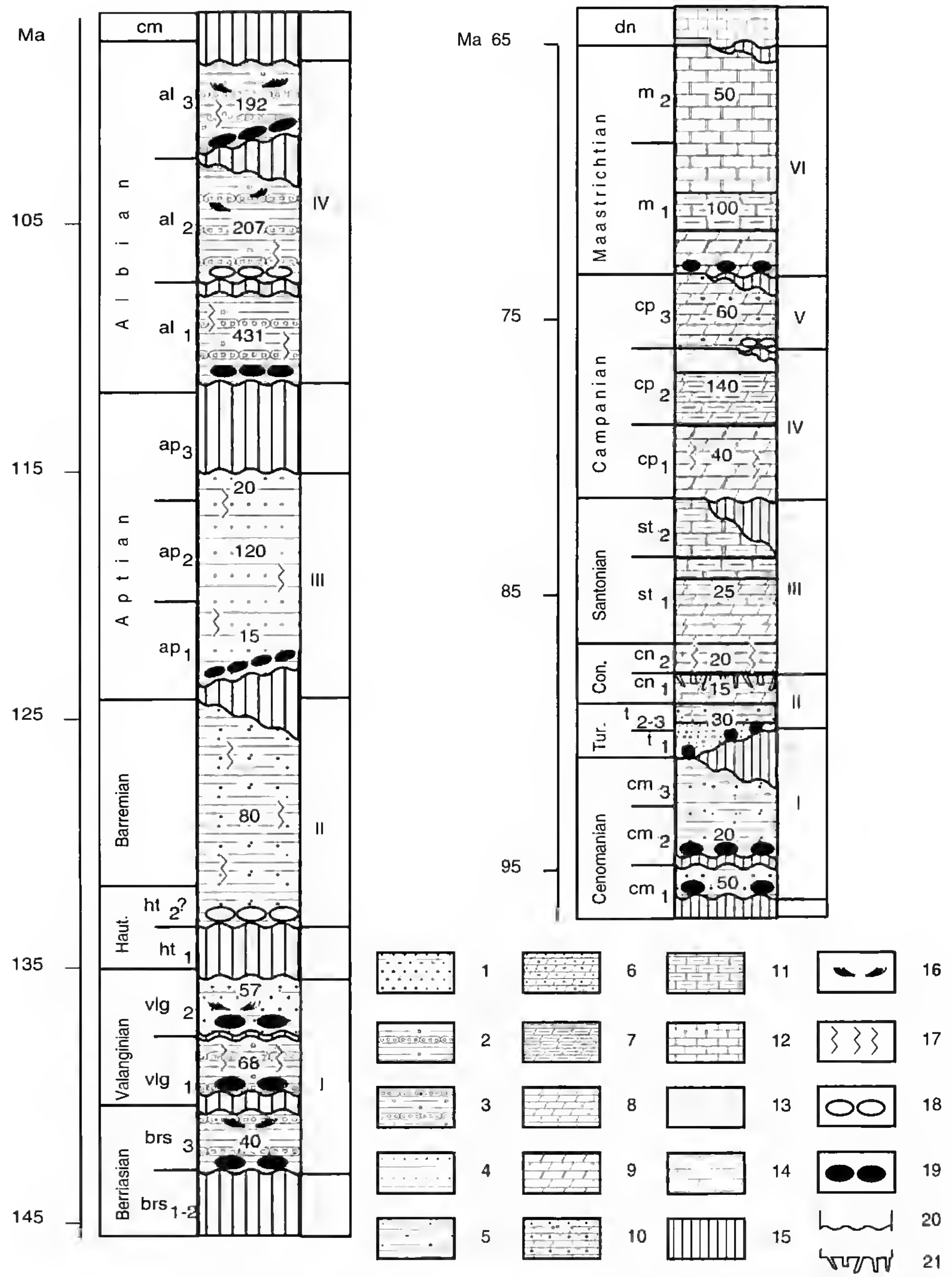

FIG. 4. — Sedimentary units of the Cretaceous of Mangyshlak. **1**, clayey sands; **2**, clays, siltstone and sandstone alternations; **3**, sands, siltstone and sandstone alternations; **4**, soft sandstones; **5**, clayey siltstones; **6**, sandy marls; **7**, clayey marls; **8**, marls; **9**, dolomitised marls; **10**, marls-sandy marl alternations; **11**, clayey dolomites; **12**, dolomites; **13**, limestones; **14**, carbonated clays; **15**, main stratigraphical unconformities; **16**, cross-bedding; **17**, bioturbation; **18**, conglomerates; **19**, phosphoric nodules and pebbles (phosphorite horizon); **20**, erosional surface; **21**, hardground. Roman numerals agree with sedimentary units.

boundaries were formed under the influence of sea-level changes, but some of them have a tectonic origin.

Unit I (Cenomanian-lower Turonian): the remains of oysters, other bivalves and phosphatic nuclei of ammonites are usually present. The foraminifera zones I-III characterise this sequence. This unit contains a very poor assemblage of benthic foraminifera, but the Cenomanian/Turonian boundary interval is characterised by large *Hedbergella-Whiteinella* planktonic foraminifera association.

Unit II (middle-upper Turonian-lower Coniacian) has a hiatus in its base. Its size is different in different parts of the area – sometimes a part of the Cenomanian or all of the middle-upper Cenomanian and the lower part of the lower Turonian are missing. There is a phosphatic horizon at the base of unit II. This is a condensed section, which was formed partly under the influence of sea-level changes (Hancock 1992). The beginning of this unit may coincide with mark 89.8 Ma in the curve of shore onlap of Haq *et al.* (1987) (Naidin 1995). Inoceramids, brachiopods, rare ammonites and echinids are present. The foraminifera zones IV-VIII characterise this succession. Benthic/planktonic foraminifera ratio is always high, but decreases near Turonian/Coniacian boundary ("Grandes Rosalines" interval).

Unit III (upper Coniacian-Santonian) was formed during an unstable eustatic situation. There is a sharp hardground surface at the base of this unit. Traces of eustatic transgression are visible towards the end of this unit, its beginning may coincide with mark 85 Ma of the main curve of Haq *et al.* (1987). This is the "Marsupites transgression" in Western Europe and in Mangyshlak. Remains of inoceramids and crinoids are usually present here. The foraminifera zones IX-XIII characterise these units. Benthic/planktonic foraminifera ratio is also high.

The boundary of units III and IV (or Santonian-Campanian boundary) shows a small condensation at this level. Belemnite rostra are abundant and remains of inoceramids are rare inside this unit (Lower Campanian). Many small echinids (*Offaster* Desor, *Galeola* Klein) are found in the lower part of this unit. The upper part is characterised by belemnites, rare ammonites and abundant small and large echinids also. Very rich assemblage of foraminifera is present, benthic foraminifera prevail. The beginning of Unit V (middle Campanian) coincides with mark 77.5 Ma. The eustatic rise of sea-level took place at this time and the transgression peak probably coincide with mark 73.5 Ma of Hancock (1992) (Naidin 1995).

Unit VI consists of chalk of Maastrichtian age in Mangyshlak. The lower boundary of this unit is different in different places: a continuous transition or a small or big hiatus in the southern Aktau Mountains. The upper Maastrichtian part of the unit has a regressive character with short transgressive impulse towards the end, so called "*elegans* transgression" (mark 67.5 or 68.5 Ma: Wicher 1953). The benthic/planktonic foraminifera ratio decreases sharply at this level. This Late Maastrichtian short but intensive transgression is clearly revealed by sedimentological and structural properties and was also shown by the last outburst in the appearance of new globotruncanid taxa (Maslakova 1978). Many different fossil remains exist in this unit: belemnites, ammonites, oysters, brachiopods, echinids. The top of unit VI coincides with the eustatic fall of the sea-level at the Maastrichtian/Danian boundary. The biological crisis is fixed at this boundary, all remains of ammonites, belemnites, inoceramids and practically all planktonic foraminifera disappeared. All the sections show a hiatus in the base of the Danian, only two Mangyshlak sections (Koshak and Kyzylsai) are marked by "boundary clay" with iridium in this interval.

CONCLUSION

From the data presented, the following stages in the development of Mangyshlak during the Cretaceous can be recognised.

1. A time of terrigenous sedimentation:

– sedimentation in a basin with longitudinal connections with strong boreal influence and smaller Tethyan invasions: upper Berriasian-Valanginian;

– sedimentation in continental conditions: upper (?) Hauterivian-Barremian;

– sedimentation in a basin with longitudinal to latitudinal connections, with Tethyan influence: Aptian;
– sedimentation in a basin longitudinal to latitudinal, but predominantly latitudinal connections with short Boreal and Tethyan incursions and with partial basin isolation: Albian;
– sedimentation in a latitudinal-oriented basin of European Palaeobiogeographic Region: Cenomanian-early Turonian.

2. A period of carbonate sedimentation in the "Chalk sea" Basin of European Palaeobiogeographic Region: middle Turonian-Maastrichtian.

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Configuration of the Palaeogene deposits of southern Russia

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ABSTRACT
Tectonic and eustatic history of the East European Plate strongly influenced the accumulation of Palaeogene sediments. Due to these factors, lower part of Palaeogene deposits is distributed in an elongated area with an axis stretches N-S, and the upper strata in an area that extends E-W. Micropalaeontological investigation of diversified Palaeogene lithofacies allowed us to subdivide and correlate Palaeocene and middle Eocene sediments of the East European (Russian) Plate and to propose the picture of its evolution during the Palaeocene-middle Eocene time.

KEY WORDS
Palaeogene,
microplankton,
stratigraphy,
palaeogeography.

RÉSUMÉ
Configuration des dépôts paléogènes de la Russie méridionale.
L'histoire tectonique et eustatique de la plaque est-européenne a profondément influencé l'accumulation des dépôts paléogènes. En relation avec ces deux facteurs, la partie inférieure des dépôts du Paléogène est répartie sur une aire allongée de direction N-S, et la partie supérieure avec une direction E-W. Les recherches micropaléontologiques sur différents lithofaciès du Paléogène nous permettent de diviser et de corréler les sédiments du Paléocène et de l'Éocène moyen de la plaque est-européenne (russe) et de proposer une image de son évolution durant le Paléocène-Éocène moyen.

MOTS CLÉS
Paléogène,
microplancton,
stratigraphie,
paléogéographie.

INTRODUCTION

Within the Russian Plate, Palaeogene deposits are classed into two lithologic types – Ukrainian and Volgian – differing essentially in lithology and stratigraphic range. Ukrainian-type sections are found to the west, and Volgian-type deposits, to the east of the Ulyanovsk-Saratov zone (Leonov 1964).

The Palaeogene deposits display an E-W zonation. As far north as the latitude of Volgograd, Palaeogene deposits are represented by all the series and show lithologic similarity to carbonate terrigenous, North Caucasus-type sections. In more northerly areas, Palaeogene sections are incomplete and are dominated by siliceous-terrigenous facies. The boundary of the area occupied by the southern, Caucasian facies coincides with the junction zone between the south flank of the East European craton and the post-Hercynian Scythian Plate.

The Figure 1 shows tectonic structure of the southern part of the Russian Plate. The diversity of Palaeogene lithologic associations is largely determined by the tectonic complexity of the study area, located in the junction zone. The North Donets thrust (Fig. 1: A) separating the East European craton and the Scythian Plate remained active throughout Cainozoic time. The southern slope of the platform is adjoined by Precambrian structures: the Ukrainian shield (Fig. 1: A) and the Voronezh uplift (Fig. 1: B) with the Dnieper-Donets aulacogen (Fig. 1: C) in-between, and by the Peri-Caspian Basin (Fig. 1: D). The Karpinsky swell (Fig. 1: E) is an E-W-trending marginal structure of the post-Hercynian Scythian Plate. This swell gives way westward to the orogenic Palaeozoic structure of the Donets area (Fig. 1: F), a constituent part of the Dnieper-Donets aulacogen (Milanovsky 1987).

The Ukrainian depression, filled by Ukrainian-type Palaeogene deposits, is a Meso-Cainozoic depression (Fig. 1: I) overprinting the south flank of the Voronezh Massif, of the Dnieper-Donets graben, and, partly, of the Ukrainian shield.

The N-S-trending Ulyanovsk-Saratov depression (Fig. 1: II), to which the Volgian-type Palaeogene deposits are confined, is related with an inversion of vertical movements. This depression evolved in Late Cretaceous-Palaeocene time, and since the Eocene it has been involved in the N-S-trending uplifting zone, presently known as the Volgian uplift. Although the Ukrainian and Ulyanovsk-Saratov depressions occur closely in space, their Palaeogene infills differ essentially in structure, stratigraphic range, and lithologic type. The zone that separating these areas extends N-S along the East Ergeny swell (Fig. 1: 4) to Don-Medveditsa swell and Kirovsk swell, and is likely to reflect a deep mantle structure that trends roughly N-S.

Throughout the Palaeogene domain, the lower beds are distributed in an elongated area whose axis stretches N-S from Ulyanovsk to Volgograd, and the upper strata gravitate to an area that extends E-W from Kiev to Volgograd. The structural rearrangement responsible for this reorientation took place in the early to early-middle Eocene.

OBJECTIVES OF STUDY

The diversity of Palaeogene lithofacies throughout this all-important area renders their stratigraphic subdivision and correlation rather difficult. Despite the long history of the studies, the micropalaeontological coverage of these deposits remains incomplete and non-uniform. This refers primarily to the stratigraphy that is based on siliceous microfossils, which abound in the Palaeocene deposits of Volgian-type sections and in the Eocene strata of Ukrainian-type sections.

First, this study sets out to constrain the stratigraphic range of Palaeogene siliceous facies in the Ulyanovsk-Saratov depression.

Second, our aim is to improve the understanding of the structure and age of the Eocene deposits in the area where the Dnieper-Donets depression adjoins the Peri-Caspian Basin, and where the Eocene strata comprise both carbonate and siliceous facies, permitting a correlation of northerly (cratonic-type) and North Caucasian sections.

Sections and boreholes penetrating the Palaeogene deposits we have studied are shown

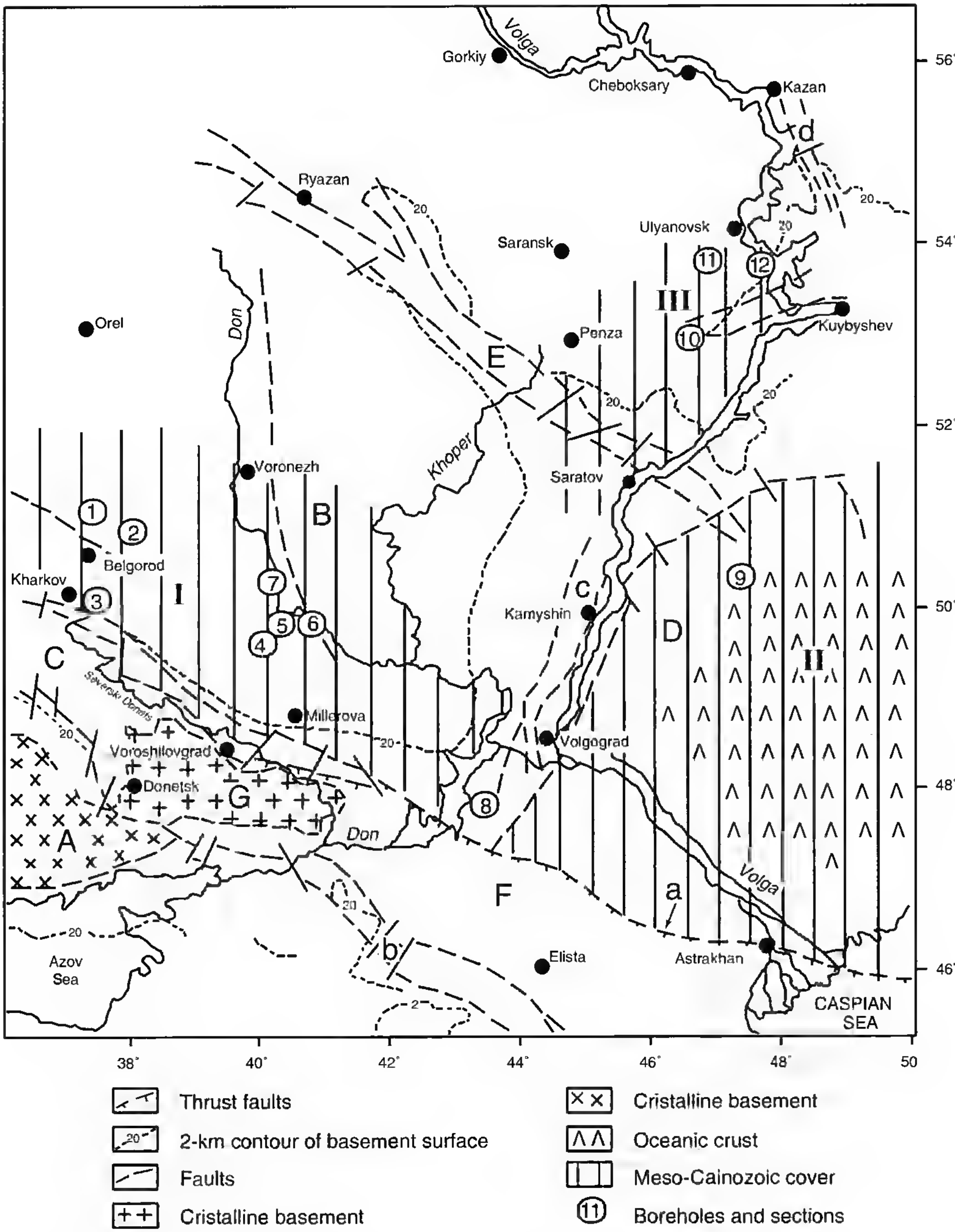

FIG. 1. — Scheme showing main tectonic structures of the southern part of Russian platform, after Geodynamic map of the USSR and adjacent seas (Anonymous 1988) and Milanovsky (1987). Boreholes and sections: **1**, Stariy Saltov; **2**, Yaruga; **3**, Strelech'e; **4**, Kantemirovka; **5**, Sergeevka; **6**, Rudaevka; **7**, Boguchar; **8**, Veshenskoe; **9**, Uzen; **10**, Smishlyaevskaya Gorka; **11**, Vodoratsky Quarry; **12**, Sengeley. Precambrian structures of the Russian Plate: **A**, Ukrainian shield; **B**, Voronezh uplift; **C**, Dnieper-Donets aulacogen; **D**, Peri-Caspian Basin; **E**, Pachelma trough; <– **a**, northern Donets thrust. Post-Hercynian structures of the Scythian Plate: **F**, Karpinsky swell; **G**, Donets folded area. Meso-Cainozoic structures: **I**, Ukrainian synecline; **II**, Peri-Caspian Basin; **III**, Ulyanovsk-Saratov synecline. Cainozoic meridional structures: **b**, East Ergeninsky swell (horst); **c**, Don-Medveditsa swell (modern Volgian uplift); **d**, Kirovsk swell.

in Figure 1. These are type sections in two areas that are crucial to Palaeogene stratigraphy in the central Ulyanovsk-Saratov depression (Sengeley, Smyshlyaevskaya Gorka, Kuroedovskie Vyselki quarry, and Vodoratsky quarry sections) and along the NE flank of the Ukrainian depression (246 Stary Saltov, 230 Strelechie, 5-93 Boguchar, and 9540 Rudaevka holes and Yaruga, Sergeevka, and Kantemirovka sections).

STRATIGRAPHIC SUMMARY OF PALAEOCENE DEPOSITS (VOLGIAN-TYPE PALAEOGENE STRATA)

Volgian-type Palaeogene deposits (Leonov 1964) have a siliceous-terrigenous composition and show a distinct cyclicity. It is customarily believed that in this region Palaeogene deposits have a complete stratigraphic range and pass continuously into lower Eocene strata.

The Palaeocene deposits are subdivided into the Syzran, Saratov (= Kamyshin), and Tsaritsyn formations. The last is assigned to uppermost Palaeocene-lowermost Eocene. However, sections in the lower and upper reaches of the Volga are difficult to correlate.. The Syzran Formation is a rather diverse and intricately built complex of clay-siliceous and sand sediments as thick as 150-180 m, grading into each other laterally from area to area. In the lower reaches of the Volga, the lithologic division into the lower (clay-gaize) and upper (sand) member is quite consistent. In the middle reaches of the Volga, the formation in places becomes tripartite, with a sandy middle member, although in places the formation consists almost entirely of diatomite and gaize [gaze (= opoka) biogenic kryptogene siliceous sediment with clayey admixture]. The Saratov (= Upper Saratov, Kamyshin) Formation is often bipartite (with the lower member consisting of gaize, and the upper, of sand), its thickness not exceeding 20-30 m. In the Volga's lower reaches, the base of this formation contains a distinct intercalation of tobacco-coloured sapropel-like clay.

The sandy Tsaritsyn Formation in the Volga's lower reaches is clearly rhythmic and consists of sandy gaize and sandstone. In the Volga middle reaches, this formation overlaps erosionally the underlying deposits, is made up of thin sand stone with occasional leaf casts, and thickens to 40-60 m.

The lithologic uniformity and cyclicity, the correlation of faunal remains with particular lithofacies, the commonly poor preservation of siliceous plankton due to diagenetic transformation of organic opal, all handicap the stratigraphic subdivision of Palaeocene deposits.

Stratigraphic range of the lithostratigraphic units (formations) is highly disputable. In this study, the paper by Khokhlova & Oreshkina (this volume) sets out to define more precisely the stratigraphic range of Palaeocene deposits in the Volga's middle reaches.

STRATIGRAPHIC SUMMARY OF EOCENE DEPOSITS (UKRAINIAN-TYPE PALAEOGENE STRATA)

The Dnieper Basin displays : (1) a reduced stratigraphic range and limited distribution of the lower Eocene strata; (2) a chiefly sandy composition of all the horizons except two: "Kiev" Horizon represented by a clay-marl member with glauconite, and the lower part of the "Kharkov" Horizon, which shows diatomite intercalations in the clay-sand member.

The correlation of stratigraphic units of the Dnieper-Donets Palaeogene strata largely depends on the dating of the "Kiev" and "Kharkov" beds. Initially, the "Kharkov" sandstones were correlated with the Lattorfian ones based on mollusks (Sokolov 1903). On these grounds, the "Kharkov" Member was assigned to the Oligocene, and the "Kiev" Member, to the upper Eocene. Later, "Kiev" was moved into the middle Eocene, and "Kharkov", into the upper Eocene (Makarenko *et al.* 1987). In some works, especially in those dealing with tectonics, this view persists still. However, after the Kiev Formation yielded the middle Eocene foraminifera assemblage of the *Globorotalia rotundimarginata* zone (Grigyalis *et al.* 1988), the stratigraphic range of the "Kiev" and post-"Kiev" strata in the stratotype area (Dnieper Basin near Kiev) became a subject of revision, and new

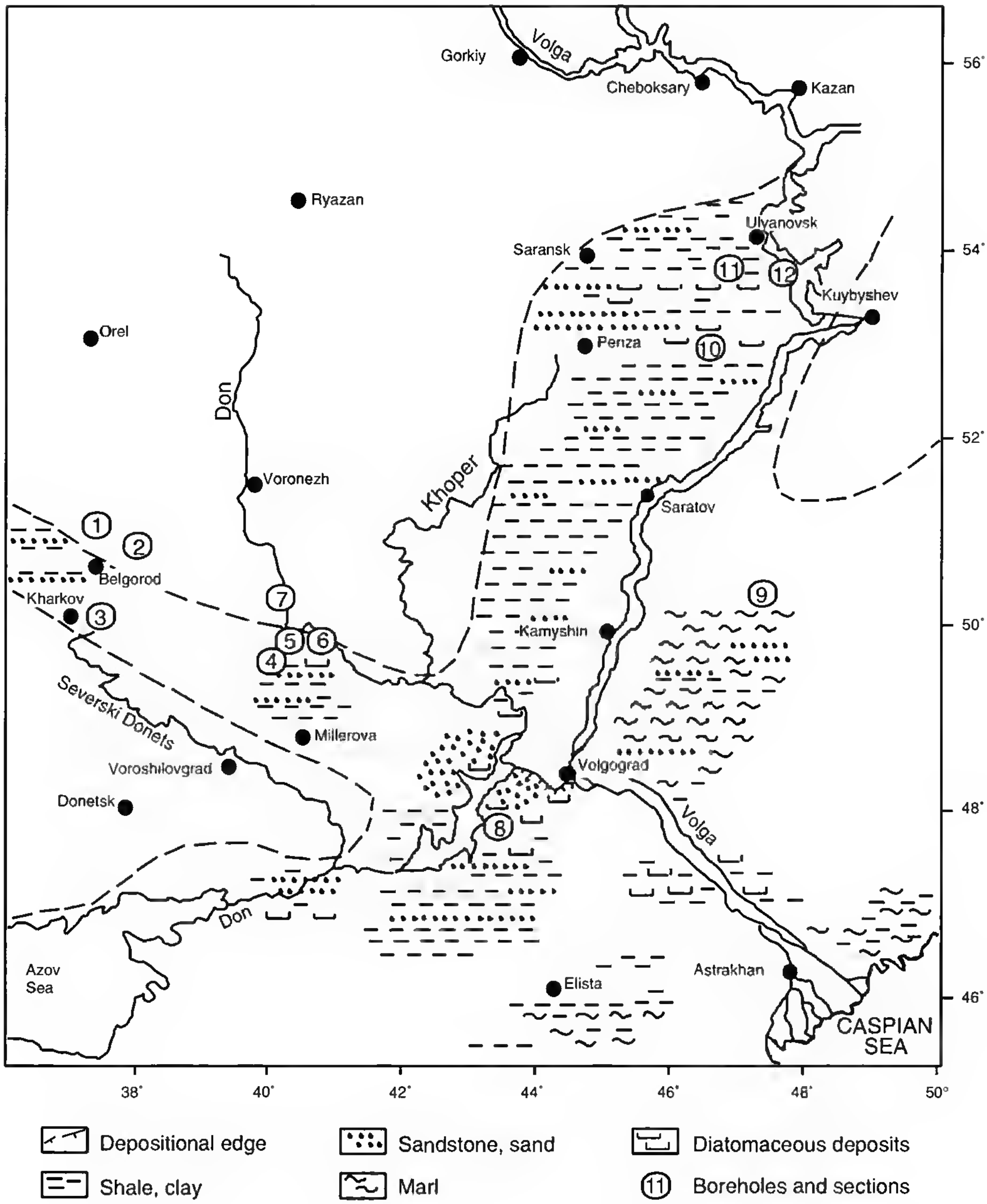

FIG. 2. — Upper Palaeocene (Thanetian) palaeogeographic scheme.

variants of their correlation with more northerly and easterly areas began to appear.

This correlation, however, is restrained by the fact that Eocene deposits change in lithology toward the northeast parts of the Ukrainian depression, where the chiefly carbonate strata in the correlates of the Kiev Formation become replaced by clay-sand deposits. In that area, another litho-stratigraphic scheme is used (Sokolov 1965).

As it was shown above, to subdivide the western-

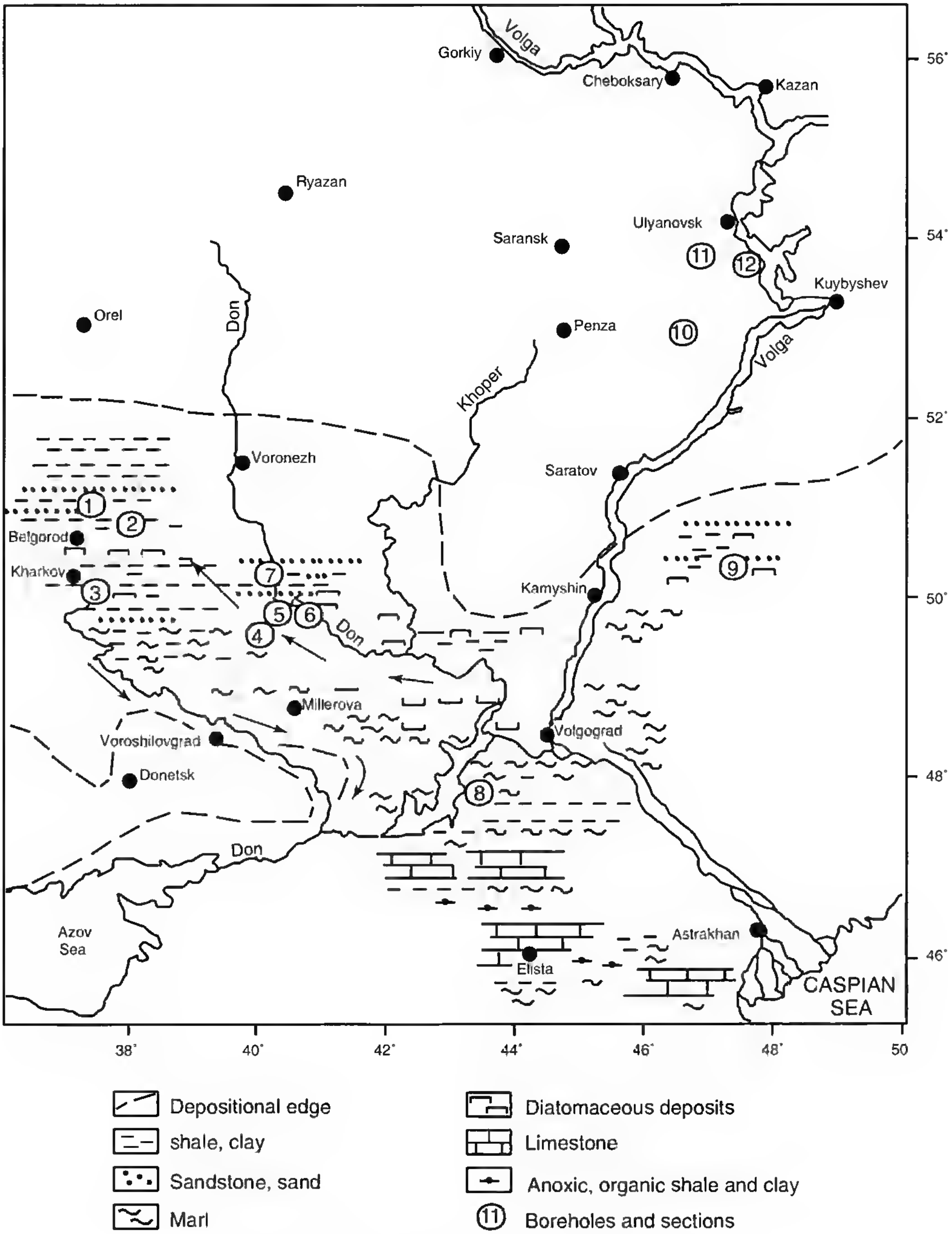

FIG. 3. — Middle Eocene (Bartonian) palaeogeographic scheme.

most section that we have studied (Boguchar), which is located in the Volga-Don interfluve, the lithostratigraphic scheme from the North Caucasus can be applied (Kurlaev & Akhlestina 1988).

In this area, the correlates of the Kuma Forma-

tion are recognised, with Bartonian anoxic events associated in eastern Peri-Tethys. The issues of stratigraphic range and facies changes in the Eocene deposits of the eastern flank of the Ukrainian depression are addressed in the paper of Khokhlova *et al.* (this volume).

PALAEOGEOGRAPHY

The Figures 2 and 3 present palaeogeographic maps showing distribution of Palaeocene (upper Thanetian) and middle Eocene (Bartonian) deposits for the southern part of the former USSR.

In late Palaeocene time, the Volga Region and Peri-Caucasian basins formed a single, shallow-water, highly productive marine basin with siliceous sedimentation (Fig. 1). Distanov (1964) proposed that Palaeocene sediments of the Middle Volga Region accumulated in a large gulf of an inland sea, with an intense upwelling process. The diatomites may have accumulated in marginal parts of palaeodeltas. Another viewpoint is that there existed seaway(s) between the Volga and West Siberian basins. This is suggested by the similarity of the faunas and floras. For example, the West Siberian assemblage consists of 100 diatom species (Anonymous 1974). More than 80% species are common with those of the Middle Volga palaeobasin.

The Middle Volga Region sagged mainly in the biosilica accumulation. Pure diatomites near the town of Sengiley contain abundant radiolarian assemblages of *Buryella tetradica* Foreman, *Tripodiscinus sengilensis* Kozlova and regional zones established by Kozlova (1984) and related to the late Palaeocene. In the northern Peri-Caspian Basin, upper Palaeocene rich radiolarians complex accompanied by nannoplankton of NP8 zone are present. In Cis-Caucasia, this level correlates to the Goryachy Klyuch and Abaza formations that contain abundant yet poorly preserved radiolarian assemblages. The entire basin had identical radiolarian assemblages, although the assemblages of the *Buryella tetradica* Foreman and *Petalospyris foveolata* Ehrenberg, in the Middle Volga sections contain a significant number of widespread tropical species.

In early Eocene time, the gulf (or seaway) that existed on the site of the middle and partly, lower reaches of the Volga, disappeared. Marine environment gave way to continental, which persisted in the Middle Volga Region into Eocene and Oligocene times. In the Dnieper-Donets Basin, lower and lower-middle Eocene strata consist of alternating terrigenous nearshore marine and continental facies. The marine basin survived only in the south – on the site of the Peri-Caspian Basin and Cis-Caucasia.

A new vast transgression was confined to the upper Lutetian-Bartonian. The outline of the basin, however, changed significantly (Fig. 3). In late Lutetian time, carbonate-terrigenous strata of the Kiev Formation were widespread in the Dnieper-Donets depression. The "Greenish Kiev Marlstone" has long been correlated with the glauconite-rich marls and limestones of the Keresta Formation in Cis-Caucasia, which contain similar foram and nannofossil assemblages. The Bartonian strata differ significantly between the southern and northern parts of the basin. Along the north and south margins of the Dnieper-Donets Basin and along the north margin of the Peri-Caspian Basin, widespread are deposits enriched in organic silica, whereas in the central part of the basin carbonate-clay sediments of the Kuma Formation, partly or entirely anoxic, were laid down. In the Volga-Don interfluve, siliceous facies giving way to the Kuma facies were attributed to the existence of the Millerovo seaway between the Donets basement high and the east slope of the Voronezh Basin (Leonov 1964).

The palaeogeography of the South Russia Basin with biosiliceous accumulation changed drastically from N-S at the time of the Selandian-lower Thanetian transgression to W-E during the Lutetian-Bartonian transgression.

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Early Palaeogene siliceous microfossils of the Middle Volga Region: stratigraphy and palaeogeography

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ABSTRACT
The Sengiley section (Middle Volga Region, Russia) provides one of the most complete late Palaeocene sedimentary sequence with well-preserved diatoms, silicoflagellates, and radiolarians. Three zones of regional zonal scheme (Kozlova 1994) based on radiolaria were distinguished in the sediments: *Buryella tetradica*, *Tripodiscinus sengilensis*, *Petalospyris foveolata* zones. Based on diatom regional scheme (Strelnikova 1992) *Trinacria ventriculosa* and *Hemiaulus peripterus* zones were recognised. Although assemblages of siliceous microfossils strongly differ from the oceanic coeval associations, the precise age of the boreal zones was determined on the basis of direct correlation with standard zonal scales of diatoms, silicoflagellates and radiolarians. For example, from sediments of *Petalospyris foveolata* zone, several species described by Nishimura (1992) from the upper part of the *Bekoma campechensis* standard radiolarian zone of the North-West Atlantic were found and allowed us to correlate these two zones. Two zones of the standard oceanic diatom scheme (Barron & Baldauf 1995) (*Hemiaulus peripterus* and *Hemiaulus incurvus* zones) and standard silicoflagellate *Naviculopsis constricta* zone were distinguished in the Sengiley section. Siliceous-terrigenous Palaeogene sediments of the Middle Volga can be considered as typical sediments of the marginal epicontinental basin. Siliceous assemblages of the Sengiley section are very close to assemblages from Lulinvort and Serov formations of the West Siberia and the eastern Urals slope, Fur Formation and Sambian Formation of North-East Europe, although the geometry of connections between these basins during late Palaeocene is still not clear.

KEY WORDS
Palaeogene, biostratigraphy, radiolaria, silicoflagellates, diatoms, Middle Volga, East European Platform.

RÉSUMÉ

Microfossiles siliceux paléogènes de la région de la moyenne Volga : stratigraphie et paléoécologie.

La coupe de Sengiley (région de la moyenne Volga, Russie) présente une des séquences sédimentaires les plus complètes du Paléocène supérieur avec des diatomées, radiolaires, silicoflagellés bien conservés. Trois zones de la zonation régionale (Kozlova 1994), fondée sur les radiolaires, sont distinguées dans les sédiments : zones à *Buryella tetradica*, *Tripodiscinus sengilensis*, *Petalospyris foveolata*. Dans la zonation régionale à diatomées (Strelnikova 1992), les zones à *Trinacria ventriculosa* and *Hemiaulus peripterus* sont reconnues. Bien que les assemblages à microfossiles siliceux diffèrent fortement des équivalents océaniques, l'âge précis des zones boréales a été déterminé sur la base de corrélations directes avec les échelles régionales standard à diatomées, silicoflagellés et radiolaires. Par exemple, pour les sédiments de la zone *Petalospyris foveolata*, plusieurs espèces décrites par Nishimura (1992) dans la partie supérieure de la zone standard à radiolaires à *Bekoma campechensis* du Nord Ouest de l'Atlantique ont été trouvées et nous permettent de corréler ces zones. Deux zones de la zonation océanique standard à diatomées (Barron & Baldauf 1995) (zones à *Hemiaulus peripterus* and *Hemiaulus incurvus*) et la zone standard à silicoflagellés à *Naviculopsis constricta* ont été trouvées dans la coupe de Sengiley. Les sédiments paléogènes siliceux-terrigènes de la moyenne Volga peuvent être considérés comme typiques de bassin marginaux épicontinentaux. Les assemblages siliceux de la coupe de Sengiley sont très proches des assemblages des formations de Lulinvort et Serov de Sibérie occidentale et du versant est de l'Oural, des formations de Fur et Sambian du Nord Est de l'Europe, bien que la géometrie des connexions entre ces bassins durant le Paléocène ne soit pas clairement établie.

MOTS CLÉS
Paléogène, biostratigraphy, radiolaires, silicoflagellés, diatomées, Moyenne Volga, Plate-forme est-européenne.

INTRODUCTION

In the Ulyanovsk-Saratov syncline of the Middle Volga Region (Fig. 1) widespread early Palaeogene sequence (approximately 300 m thick) is represented by marine siliceous-terrigenous deposits with high facies diversity. Previous stratigraphic subdivision of Palaeogene sequences was based in most cases on the lithological data. The age of these subdivisions and relations between them have been revised by different investigators more than once (Milanovsky 1940; Leonov 1961; etc.). The high abundance of siliceous facies, opokas (kryptogene siliceous deposits), the diatomites, siliceous clays and sands offer advantage for siliceous microfossils study.

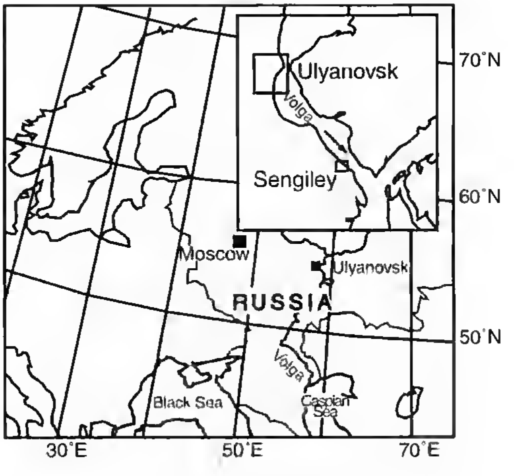

Fig. 1. — Location of studied Sengiley section.

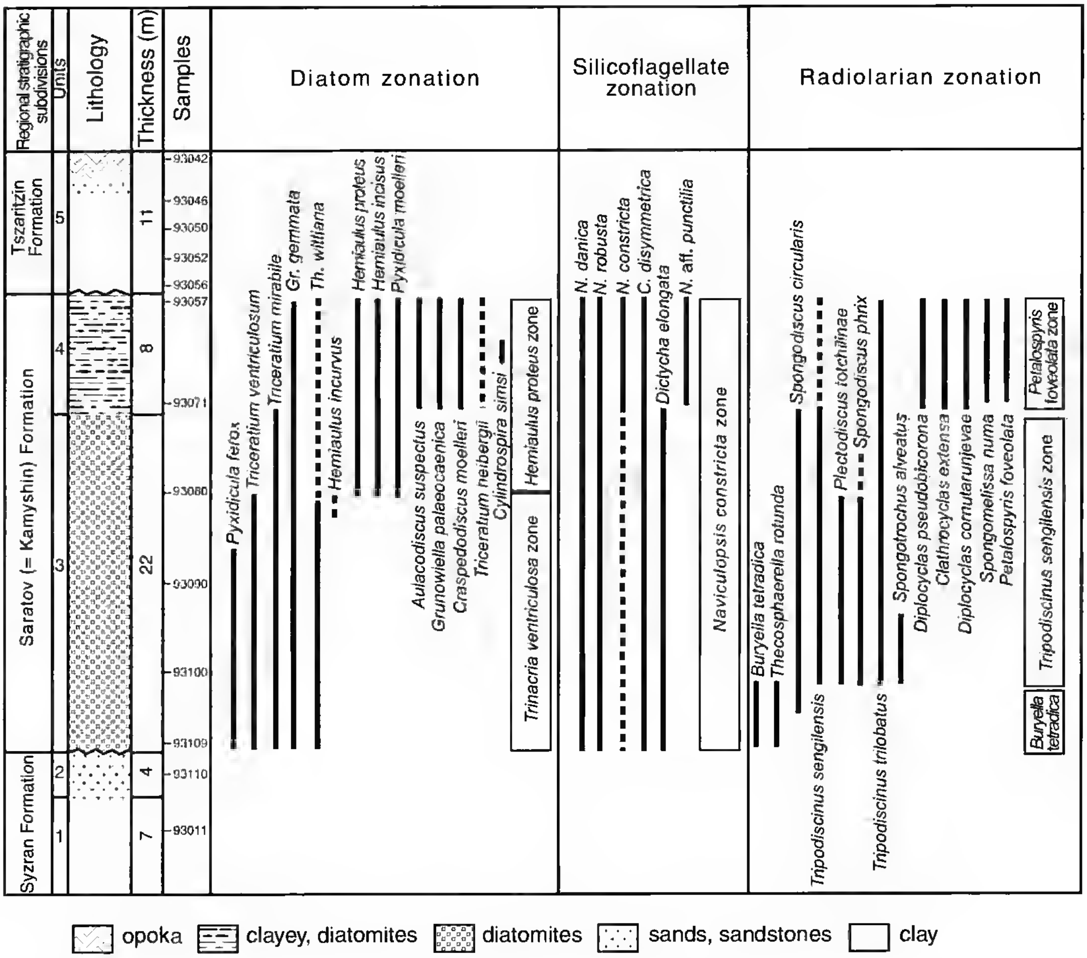

FIG. 2. — Lithology and lithostratigraphy of the Sengiley section, stratigraphic ranges of siliceous microfossils, and zonation. Schemes of Strelnikova (1992) (diatoms), Locker & Martini (1987) (silicoflagellates) and Kozlova (1994) (radiolarians) were used.

This paper seeks to examine the evidence provided by siliceous microfossils – diatoms, silicoflagellates and radiolarians which occur in the Sengiley section. Study of siliceous microorganisms from this section is very crucial for precise age determinations of Palaeogene sedimentary cycles and for revealing conditions of silica accumulation on the northern Peri-Tethyan margin. The problem of relations between these early Palaeogene biosilica accumulation events and regional and global geological events is also of great interest.

SENGILEY SECTION

The Sengiley section (Figs 1, 2) is located 7 km north-west of the Sengiley (Ulyanovsk Region). On the right bank of the Volga River, at an elevation of approximately 300 m above sea level, a section of 40 m high cliff so-called "Granoe Ukho" was studied. Up to the section the following lithological units were distinguished in the studied interval:

– at the river bank below the cliff siliceous grey clays of 7 m thickness; no microfossils found.

– siliceous dark-grey sandstones, thin-layered, with silica clays lenses, lie at the base of the diatomite cliff; thickness 4-4.5 m; no microfossil found.
– white massive diatomites with layers of light-grey diatomites, sometimes with glauconite; thickness 22 m; in samples 930109-930072 abundant siliceous microfossils were found.
– light-grey massive clayey diatomites lying conformably on the underlying unit; thickness 7 m; samples 930072-93057 contain abundant siliceous microfossils.
– the unconformity separates the diatomite units from overlying sediments; they are represented by sandy brownish-green clays, siliceous greenish-grey sands, brownish sandy opokas, silica dark-grey opokas; thickness about 11 m. Microfossils were not found.

PREVIOUS STUDY OF SILICEOUS MICROFOSSILS

Zonal subdivision of the Sengiley section on the basis of radiolarians has been proposed by Kozlova (1984). The age was considered as late Palaeocene. Radiolarian zones of this scheme are undoubtedly regional and can be traced in the boreal epicontinental Palaeogene of the Volga and Ural regions.
The study of diatoms of the Middle Volga Region was started in 19th century by Ehrenberg (1854), Grunow (1884) and Witt (1896). Later, diatoms and silicoflagellates from this location have been studied by Leonov (1961), Jousé (1979, 1982), Gleser (1993, 1995; Gleser *et al.* 1977) and Strelnikova (1990, 1992). The lower part of the diatomite unit is certainly related to the Palaeocene by all investigators, but an early Eocene age is still nor excluded for the upper part of diatomites. Silicoflagellate assemblages from several separated samples from the Sengiley section were studied and dated by Locker & Martini (1987) as early Eocene.

MATERIAL AND METHODS

Samples were collected during a field trip of Russian Academy of Sciences Geological Institute in 1994. 81 samples were examined for diatom and radiolarian biostratigraphy, but siliceous micro-organisms were found only in 55 samples from the diatomite units of the section. Sampling interval was approximately 50 cm.
Approximately 5 g of sample was crushed mechanically and placed into an 400 ml beaker. Then samples were processed by 15-minutes boiling in hydrogen peroxide. The procedure of repeatedly filling and decanting the beakers with distilled water and allowing 2 hr settling was used to remove chemicals and clay minerals.
Slides for radiolarian study were prepared on 24 × 24 mm cover glasses and mounted in Canadian balsam on 24 × 80 mm glass slides. Radiolarians were examined at × 400. Species were recorded as abundant (A) if more than 10 specimens were present in the slide, common (C) if 3-10 specimens occurred in the slide and rare (R) if 1-3 specimens were found.
Strewn slides for diatoms were prepared by sampling the suspended residue with a pipette spreading it on 18 × 18 mm cover slide and mounting in Elyashev mounting medium. Diatoms were examined at × 500. Species identification was checked at × 1250. Some samples were studied in SEM "Cambridge Stereoscan" microscope. Relative abundance of taxa represented in the range chart is reported as abundant (A) when 20 specimens are present in one horizontal traverse at × 500, common (C) when 3-19 specimens are present at each traverse, few (F) – 1-2 specimens in each traverse, rare (R) – less than one specimen in each traverse.

STRATIGRAPHY

Radiolaria

Using radiolaria, the section was subdivided on the basis of the boreal zonal scheme of Kozlova (1994). The zonal succession is Palaeocene (Fig. 1, Table 1).

Buryella tetradica zone
The assemblage is moderately preserved and contains *Buryella tetradica* Foreman, *Thecosphaera rotunda* Borissenko, *Spongotrochus puter*

TABLE 1. — Stratigraphic distribution of radiolaria in Sengiley section. **A**, abundant (20 specimens are present in one horizontal traverse examined at × 500); **C**, common (3-19 specimens are present at each traverse); **F**, few (1-2 specimens in each traverse); **R**, rare (less than 1 specimen in each traverse).

AGE	ZELANDIAN																	
ZONE	*Buryella tetradica*		*Tripodiscinus sengilensis*															
Species / sample number	109	108	107	106	105	104	103	102	101	100	99	98	97	96	95	94	93	92
Buryella tetradica	C	C	C	R														
Lophophaena curta			R	R	C	C	R	R										
Plectodiscus totchilinae				C	C	C	R	R										
Spongodiscus americanus			A	A	A	A	C											
Spongodiscus phrix			C	R	C	C	C	R										
Spongotrochus alveatus							C	C		R		R						
Spongotrochus sp. aff. *Trochodiscus cleve*							A	C										
Spongotrochus aff. *helioides*										A	A	A	A	A	A	C	C	C
Spongotrochus paciferus					R		R			R		R						
Spongotrochus puler		C	C	C														
Thecosphaera rotunda		R	R	R														
Tripodiscinus sengilensis				C	C	C	C	C	R		R		R					
Tripodiscinus sibiricus		R	R	R			R	R	R	R	R	R	R					
Tripodiscinus trilobatus						R	R								R			

AGE	ZELANDIAN-THANETIAN																	
ZONE	*Tripodiscinus sigilensis*																	
species/sample number	91	90	89	88	87	86	85	84	83	82	81	80	79	78	77	76	75	74
Anthocyrtoma frizzeli					R		R											
Lamocalpis smili											C	R	R					
Lophophaena curta												R				R		
Phormocyrtis reticula											C	R						
Plectodiscus totchilinae					C	R											R	
Spongotrochus aff. *helioides*	C	R	C	C														
Spongomelissa ternaria					R	R						R						
Tropodiscinus trilobatus					C	C	C	R	C	R	R	R	R	R	R	R	C	
Tripodiscinus sengilensis		R			R													R

AGE	ZELANDIAN-THANETIAN						THANETIAN											
ZONE	*Tripodiscinus sigilensis*						*Petalospyris foveolata*											
species/sample number	73	72	71	70	69	68	67	66	65	64	63	62	61	60	59	58	57	
Acanthosphaera sp.										C	C	C						
Botryometra cena												C	R	C		R		
Clathrocyclas extensa										R		R						
Clathrocyclas lipmanii										R	R							
Clathrocyclas longispina									A									
Diplocyclas cornuta runjevae						C	R		R	A	R	C	C					
Diplocyclas pseudobicorona pseudobicorona						R	C	C			R	C						
Periviator (?) dumitricae											R	R	R					
Petalospyris foveolata						R	R	C	C	C	C	R						
Spongasteriscus cruciferus						R	R			C	R							
Spongomelissa ternaria							C					R	R	R		R	C	
Spongomelissa numa numa						R	C					C						
Spongotrochus nativus praecox									A									
Stylodyctya harlestonensis							R		R	A		R	C	R				
Tripodiscinus trilobatus		R								R								

Kozlova, *Tripodiscinus sibiricus* Kozlova, *Spongodiscus americanus* Kozlova, *Spongodiscus phrix* Gorbovetz and *Lophophaena curta* Kozlova. The base of the zone was not observed in the section. The upper boundary is determined by the appearance of *Tripodiscinus sengilensis* Kozlova and *Plectodiscus totchilinae* Kozlova.

Tripodiscinus sengilensis zone
Radiolarians are abundant and well-preserved. The most common are: *Tripodiscinus sengilensis* Kozlova, *T. trilobatus* Kozlova, *Lophophaena curta* Kozlova, *Spongotrochus paciferus antiquus* Kozlova, *S.* aff. *Trochodiscus clevei* (Kozlova), *S.* aff. *helioides* Cleve, *Spongodiscus americanus* Kozlova & Gorbovetz and *Plectodiscus tochilinae* Kozlova. *Sponotrochus alveatus* Riedel & Sanfilippo, *Tripodiscinus sibiricus* Kozlova, *Stylodictya charlestonensis* (Clark & Campbell), *Anthocyrtoma frizzeli* Nishimura and *Periviator*(?) *dumitricae* Nishimura occur rarely. Common *Larnocalpis smili* Middour and *Phormocyrtis reticula* Kozlova & Gorbovetz were found in the upper part of the zone. The upper boundary of the zone is very sharp and determined by the appearance of *Petalospyris foveolata* Ehrenberg, *Diplocyclas cornuta runjevae* Kozlova, *D. pseudobicorana pseudobicorona* Nishimura, *Spongomelissa numa numa* Kozlova, *Clathrocyclas longispina* Clark & Campbell and *Spongotrochus nativus praecox* Kozlova.

Petalospyris foveolata zone
Radiolarians are diversified and well-preserved. The most abundant are: *Petalospyris foveolata* Ehrenberg, *Dyplocyclas cornuta runjevae* Kozlova, *D. pseudobicorona pseudobicorona* Nishimura, *Antocyrtoma frizzeli* Nishimura, *Botryometra osha* Kozlova, *Spongomelissa ternaria* Kozlova, *S. numa numa* Kozlova. In the lower part of the zone *Clathrocyclas longispina* Clark & Campbell, and *Spongotrochus nativus praecox* Kozlova are abundant. *Spongasteriscus cruciferus* Clark & Campbell, *Clatrocyclas extensa* Clark & Campbell and *C. lipmanii* Kozlova are rather rare.

DIATOMS AND SILICOFLAGELLATES
Pronounced taxonomic changes in diatom assemblages observed in the middle part of Sengiley diatomites (Fig. 1, Table 2) allow us to distinguish from the base and upsection two zones of the zonal scheme for the Northern Hemisphere *sensu* Strelnikova (1990, 1992).
Trinacria ventriculosa zone is represented by common *Triceratium mirabile* Jousé, *Trinacria ventriculosa* (A. Schmidt) Gleser, *Pyxidicula ferox* (Greville) Strelnikova & Nikolaev, *Grunowiella gemmata* (Grunow) Van Heurck. The assemblage of the Hemiaulus proteus zone consists of *Hemiaulus incurvus* Shibkova, *H. proteus* Heiberg, *H. incisus* Hajos, *H. frigidus* (Grunow) Fenner, *Soleum ex-sculptum* Heiberg, *Triceratium heibergii* Gombos, *Craspedodiscus moelleri* A. Schmidt, *Aulacodiscus suspectus* A. Schmidt, *Grunowiella palaeocaenica* Jousé and *Cylindrospira simsi* Mitlehner.
Besides the stratigaphically important species enumerated above, diversified representatives of the neritic diatom flora of epicontinental basins are present in both zonal assemblages. A full list is shown in the Table 1 and in the taxonomic appendix.
Silicoflagellates (about 10 taxa) are common throughout the whole section. For stratigraphic subdivision, the zonation of Locker & Martini (1987) is applied. The appearance of members of the *Naviculopsis* genus (including *N. constricta* (Schulz) Frenguelli, *N. robusta* Deflandre, *N. danica* Perch-Nielsen) defines *Naviculopsis constricta* zone (upper Palaeocene-early Eocene). *Corbisema disymmetrica* Bukry is present throughout the whole section. According to Locker & Martini (1987), this stratigraphic interval corresponds to the NP4-NP9 nannoplankton zones and so gives us the possibility to restrict the age of the diatomite unit by the Palaeocene. Less pronounced than diatoms one, change in taxonomic composition is related to the middle part of the section. This reconstruction includes the last appearance of *Dictyocha elongata* Gleser and the first appearance of *Naviculopsis punctilia* Perch-Nielsen.

PALAEOECOLOGY

Radiolarian assemblages are well preserved and, for the epicontinental setting, diversified (33 spe-

TABLE 2. — Stratigraphic occurrence of diatoms and silicoflagellates in Sengiley section. Legend: see Table 1.

Diatoms/Samples	109	108	107	106	105	104	103	102	101	100	99	98	97	96	95	94	93	92	91	90	89	88	87	86	85	84
Aulacodiscus distinguendus										R									R						R	
Aulacodiscus probabilis										R									R			R				
Briggera sibirica	R					R		F		R	R	R	F	R	R		R	R	R	R	R					R
Costopyxis antiqua							R			R																
Eunotogramma variabile	R	R	R	R	R	R	R				R			R		R	R			R		R	R		R	
Eunotogramma weissii	F	F	F						R	C																
Grunowiella gemmata	C	A	C	C	A	A	C	C	C	C	F	C	F	F	F	C	C	F	F	C	C	A	C	C	A	A
Hemiaulus frigida	C	R	R	R	R	R	C	R	R	R	C	R	C	R	R	R	R	R	R	R	R	R	R	R		R
Hemiaulus ambiguus																									F	R
Hemiaulus danicus			R	F	F	R				R												R				
Hemiaulus incurvus																									R	
Hemiaulus rossicus																									F	F
Hyalodiscus radiatus	R	R	F	R	R	R	R	F	R	R	R	R	R			R	R		R	R						
Kentrodiscus fossilis																R	R								R	R
Lisitzinia distanovii																					R		R			
Odontotropis carinata	R				R	R	F	F	F	F	F	F	F	F	R	F	F	R	R	R	R	R	R	R	R	R
Odontotropis cristata								R	R	R	R				R		R		R	R						
Paralia crenulata		R		F			F				R	R	R		R	R	R	R	R	R						
Paralia grunowii								F	F	R	R	R	R		R	F	R	R	R	R	R	R	R	R	R	R
Paralia sulcata	R	F	R	F	R	R	F	F	F	F	F	F	F	F	F	F	F	F	F	F		R		F		
Proboscia cretacea	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	R	R	R	R	R	R
Pseudopodosira sp. 2																							F	R		
Pseudopodosira westii	R	F	R			R	R	R	R	R	R	R	R	R	R	R		R	R	R	F	F	F	F	F	F
Pseudostictodiscus angulatus	R	R	R	F	R	R	R	R	R	R				R		R	R	R	R	R	R		R	R	R	R
Pterotheca major	R						R			R												R			R	R
Pyxidicula ferox	C	C	C	C	C	C	C	C	C	C	F	F	F	F	F	F	F	F	F	F	F	F	F			
Rattrayella oamaruensis																			R	R			R			
Rhaphoneis morsiana																								R		
Rhaphoneis simbirskiana																									R	
Rhizosolenia hebetata			R																							
Stellarima microtrias	F	R	F	F	R	R	R	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
Thalassiosira sp. 1							R																R			
Thalassiosiropsis wittiana	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	F	F	C	C	C	C
Triceratium tios										R																
Triceratium kinkeri	R	R	F	R	R	R	R	R	R	R	F	F	F	F	R	R	R	R	R	R	C	C	C	C	C	C
Triceratium mirabile	C	C	C	C	A	A	C	A	A	A	A	A	A	A	A	A	A	C	C	C	R	R	F	R	F	F
Triceratium ventriculosum	F	C	F	F	C	F	F	F	F	F	F	F	R	R	F	R	R	F	F	F	R	R	F	R	R	R
Trinacria pileolus	R	R	R	R	R	R	R	R	R	R	R	F	R	R	F	F	F	F	F	F	R					
Trochosira spinosa			R		R			R			R				R						R		R			
Silicoflagellates																										
Corbisema disymmetrica communis	R	F	R	F	F	F	R	F	F	F	F	F	F	F	F	F	F	R	R	R	R	R	R	R	R	R
Corbisema hastata hastata	F	F	F	R	R	F	F	F	F	F	C	C	C	C	C	C	C	C	C	C						
Corbisema hastata globulata																					R	R	R	R	F	R
Corbisema inermis inermis	R	R	R	R		R	R	R	R	R	F	F	R	R	R	R	R	R	R	R	F	F	F	R	R	F
Dictyocha elongata	C	F	F	F	F	F	F	F	F	F	C	C	C	C	C	C	C	C	C	C	F	F	R	F	R	R
Dictyocha fibula	R		R				R				R	R				R	R	R	R	R	R	R	R	R	R	R
Dictyocha precarentis										R	R	R	R	R			R	R		R		R			R	R
Naviculopsis constricta	R	R										R					R			R	R	R	R			
Naviculopsis danica													R			R				R						
Naviculopsis robusta	R	R			R			R		R	R	R		R		R	R		R	R	R			R		

Diatoms/ Samples	83	82	81	80	79	78	77	76	75	74	73	72	71	70	69	68	67	66	65	64	63	62	61	60	59	58	57
Aulacodiscus distinguendus			R	R				R			R				R			R			R						
Aulacodiscus probabilis	R			R		R	R	R	R	R	R	F	F	F			R		R		R			R			R
Aulacodiscus schmidti		R			R				R	F							R		R							R	
Aulacodiscus suspectus												R	R	R	F	F	C	C	C	C	C	C	F	C	A	A	F
Briggera sibirica		F		R		R			R					R				R								R	
Craspedodiscus moellari												F	F	F	F	F	C	A	A	C	A	A	C	C	A	A	F
Cylindrospira simsi																	R	R	R	C							
Eunotogramma variabile		R	R	R																							
Eunotogramma weissii						R				R																	
Fenestrella antiqua												R						R									
Grunowiella gemmata	C	C	C	F	F	F	R	F	F	F	F	F	F	F	F	F	F	F	F	C	F	F	F	F	F	F	F
Grunowiella palaeocaenica												R	C	C	C	C	C	C	C	C	C	C	C	C	C	C	F
Hemiaulus ambiguus	R			R		R				R				R		R											
Hemiaulus arcticus var. *bornholmensis*			F			R			R		R		R		C	R	R	R	R	R	R	R	R	R	R	R	R
Hemiaulus curvatulus																	F	R	R	F	F	F	F	F	F	R	R
Hemiaulus danicus														R	R		R								R	R	R
Hemiaulus frigidus	R	R	R	R	R		R		R		R				R												
Hemiaulus incisus			R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Hemiaulus incurvus			R	R																							
Hemiaulus proteus				F	C	C	C	C	C	C	C	C	C	C	C	C	C	F	A	A	A	C	A	A	C	C	F
Hemiaulus rossicus		R		R													R	R									
Hyalodiscus radiatus	R		R			R		R	R	R	F	R	R	R		R	F	R	R	R	R	F	R	R	R	R	R
Kentrodiscus fossilis																		R			R						
Lisitzinia distanovii														R	R			R									
Odontotropis carinata	R	R	R	R					R	R	F	F	R	F	R	R	R	R	R	R	R	F	R	F	R	R	
Odontotropis cristata													R				R					R					
Paralia crenulata	R	F	F	C	C	C	F	F	R	R	F	R	R	R	R	R	R	F	R	R	F	R	R	R	R	R	R
Paralia grunowii	F	F	R	F	F	F	F	F	C	C	C	R	R	R			R	R				R	R	R	F	R	R
Paralia sulcata	F	C	C	A	A	A	A	A	F	F	F	F	A	A	A	A	A	F	F	F	F	F	A	A	A	C	R
Proboscia cretacea	R	R	R	R	R	F	R	R	F	F	R	F	F	F	R	R	R	R	R	F	R	R	R	R	R	R	R
Pseudopodosira sp. 2		F	F	R																			R	R			
Pseudopodosira westii	F	F	A	A	C	C	C	F	F	R	R	R	R	R	R	F	R	R	F	R	R	R	R	R	R	R	R
Pseudostictodiscus angulatus		R	R	R		R	R		R	R	F	R	R	R	R	R	F	F	R	R	F	R	R	R	R	R	
Pterotheca major			R				R							R			R							R			
Pyxidicula moelleri			R	F	F	F	F	F	F	F	C	C	C	C	C	F	C	F	F	F	C	C	C	C	C	F	R
Rattrayella oamaruensis											F							R			F						
Rattrayella rotundata					R				R		R								R		R			R			
Rhaphoneis morsiana	F				R							R				R						R			F	R	R
Rhaphoneis simbirskiana			F		F				F	R	F	F	F	F	R	F	F	F	F	R	F	C	C	C	F	F	R
Rhizosolenia hebetata					R					R		R					R										
Solium exsculptum		R	F	F	F	F	F	F	F	F	R	R	F	F	F	R	R	F	F	F	R	R	F	F	F	R	R
Stellarima microtrias	R	F	F	F					R	R	R	F	F	F	R	R	F	F	R	R	R	F	F	F	R	R	R

Diatoms/ Samples	83	82	81	80	79	78	77	76	75	74	73	72	71	70	69	68	67	66	65	64	63	62	61	60	59	58	57
Thalassiosira sp. 1																								R			
Thalassiosiropsis wittiana	C	C	C							R				R			R						R				
Triceratium flos										R	R	R		R	F	F											
Triceratium heibergii												F	R	R	R	R	R	F	F	F	R		R		R	R	
Triceratium kinkeri	F	F	R	R																							
Triceratium mirabile	R	R	R	R	R	R	R	R	R	R	R	R	R						R	R	R				F	R	
Triceratium sparsipunctata					R										R	R	R			R		R					
Triceratium ventriculosum	R	R																									
Trinacria excavata		R	R	R	R	R	R	R	R	R	R	R	R	R	R	F	F	F	C	C	C	C	C	C	F	R	
Trinacria pileolus	R				R				R						C	C	C	C	C	C	C	C	C	C	C	C	R
Trinacria regina			R							R			R		R				R			R	R		R	R	
Trochosira spinosa	R								R			R							F	R				R	R		
Xanthiopyxis sp. 1												R	R	R													
Silicoflagellates																											
Corbisema disymmetrica communis	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Corbisema hastata hastata															R	R	F	R	R	F	F	F	F	F	R	R	R
Corbisema hastata globulata	F	F	F	R	R	R	R	R	R	F	F	F	F	F	R	R	R								R	R	
Corbisema inermis inermis			R			R			R		R			R													
Dictyocha elongata	R	R	R	R	R	R	R	R	R	R	R	R	R														
Dictyocha fibula	C	F	R				R				R			R													
Dictyocha precarentis	R		R				R				R				R	R			R	R				R	R		
Naviculopsis constricta					R					R	R		R	R	R	R	R	R			R				R	R	R
Naviculopsis danica	R		R		R		R		R	R		R		R			R					R		R			
Naviculopsis punctilia													R	R	R	R	R		R			R			R		
Naviculopsis robusta		R				R		R	R	R	R																

cies were determined). Different radiolarian species dominate the assemblage in specific stratigraphic intervals. For example, specimens of *Spongodiscus americanus* Kozlova & Gorbovetz dominate in the lowermost part of section (samples 109-104), *Tripodiscinus sengilensis* Kozlova in samples 106-101, *Spongotrochus* aff. *helioides* (Cleve) in samples 99-88, *Tripodiscinus trilobatus* Kozlova in samples 87-75, *Anthocyrtoma frizzeli* Noshimura and *Petalospyris foveolata* Ehrenberg in samples 65-60. Generally, in the lower part of diatomite unit, representatives of the Spongodiscidae family (genera *Spongodiscus* and *Spongotrochus*) and Trissocyclinae family (genus *Tripodiscinus*) are dominant, and in the upper part of diatomites specimens of the *Cyrtidae* (genera *Diplocyclas*, *Clathrocyclas* and *Anthocyrtoma*) and of the Spyridae (genus *Petalospyris*) dominate. The greatest change of the association can be observed at the stratigraphical level of samples 72-67 (Fig. 2), on the boundary between the *Tripodiscinus sengilensis* and *Petalospyris foveolata* radiolarian zones.

Diatom assemblages are well preserved and taxonomically diversified too, represented mainly by robust, large frustules of diatoms. About 60 taxa of diatom were determined. The diatom assemblages are dominated by species typical for neritic environment. Fully planktonically living species are represented by genera *Hemiaulus*, *Rhizosolenia*, *Proboscia*, *Thalassiosiropsis* and *Triceratium*.

In the upper part of the section (samples 80-71) a taxonomic turnover in diatom assemblages correlates with relative increase of the *Paralia sulcata* (Ehrenberg) Cleve group. It is possible that these changes testify the transition to the coastal, shallower environment. The same trend is reflected in the increasing of clayey material content in the upper part of the section and in the change of diatomites colour from white to grey.

DISCUSSION

STRATIGRAPHIC ISSUES

The precise age determination of siliceous

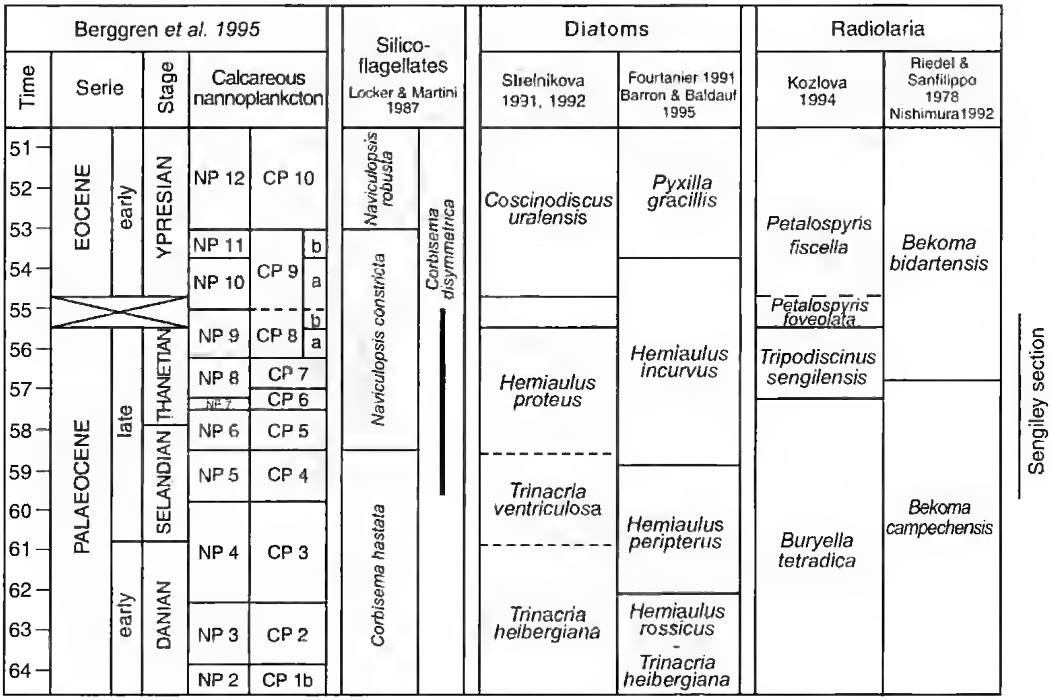

FIG. 3. — The stratigraphic position of the diatomites of the Sengiley section and correlation to standard and regional zonal schemes.

microfossils associations from the diatomite unit of the Sengiley section is very important to understand the stratigraphic position of the Middle Volga siliceous sediments (Fig. 3).

Present knowledge of stratigraphic ranges of Palaeocene diatoms and radiolarians is very limited, especially for the epicontinental basins. As a rule sediments do not contain any calcareous plankton and do not have not any palaeomagnetic data.

Besides in the Volga Region, the *Buryella tetradica* radiolarian zone can be distinguished in the North Precaspian Basin; the *Tripodiscinus sengilensis* zone can be observed in the Serov Formation of the eastern Ural slope and of the western Siberia; and the *Petalospyris foveolata* radiolarian zone can be recognised in the Irbit Formation of the eastern Ural slope (Kozlova 1984). These radiolarian zones are thus regional and can be traced across a wide territory.

Radiolarian zones distinguished in this paper were referred to the upper Palaeocene by Kozlova (1994) on the basis of a few species common to the associations from the Gulf of Mexico (Foreman 1973).

We suggest that the *Buryella tetradica* and *Tripodiscinus sengilensis* zones are related to the lower *Bekoma campechensis* zone of the standard radiolarian scale, in regard of the presence of *Buryella tetradica* Foreman, *Thecosphaera rotunda* Borissenko, *Spongodiscus americanus* Kozlova & Gorbovetz, *Spongotrochus alveatus* Riedel & Sanfilippo and *Periviator* (?) *dumitricai* Nishimura. Based on the presence of *Diplocyclas pseudobicorona pseudobicorona* Nishimura, *Spongasteriscus cruciferus* Clark & Campbell and *Anthocyrtoma* (?) *frizzelli* Nishimura, the *Petalospyris foveolata* zone seems to correspond to the upper part of *Bekoma campechensis* zone of the Northwest Atlantic and, correspondingly, to the CP5-CP6-lower CP7 nannoplankton zones (Nishimura 1992).

A similar picture is obtained from the diatom stratigraphy. The same succession of diatom assemblages (*Trinacria ventriculosa* and *Hemiaulus proteus* zones) is typical for the whole

region, being reported from the boundary interval between the lower and middle parts of the Lulinvort Formation (Pur and Taz River basins) of western Siberia, the Irbit and Serov formations of the eastern Ural slope (Proshkina-Lavrenko 1974). Unfortunately, the precise age of these regional subdivisions remains unclear, for they can still not be correlated with the standard zonal schemes of calcareous microplankton. Strelnikova (1990, 1992) puts the foregoing zones into the late Palaeocene. Gleser (1994, 1995), the first who distinguished these zones, considered the lower zone as late Palaeocene and upper one as early Eocene. But, it is clear now, that for the subdivision of the Sengiley section, standard diatom zones, which were directly correlated with nannoplankton zones in sections from southern Indian Ocean (Fourtanier 1991; Barron & Baldauf 1995) can be used (Fig. 3).

The taxonomic composition of the upper *Hemiaulus proteus* zone is like that of the *Hemiaulus incurvus* standard zone. The sharply different assemblage of the lower *Trinacria ventriculosa* zone allows us to correlate this interval to the *Hemiaulus peripterus* zone. These standard diatom zones correspond to the NP4-NP11 nannoplankton zones (Fig. 2). However, the presence in all associations of the silicoflagellate *Corbisema disymmetrica* Bukry, which is known only from the NP4-NP9 interval, allows us to suggest that the Sengiley diatomites are within the Palaeocene.

Thus, in all three (radiolarian, diatom, and silicoflagellate) assemblages, there are a number of stratigraphic markers which can be successfully used for the stratigraphic subdivision of early Palaeogene sediments and for the refinement of Palaeocene diatom zonation. These are the diatom species *Aulacodiscus suspectus* A. Schmidt, *Hemiaulus proteus* Heiberg, *Craspedodiscus moelleri* A. Schmidt, *Cylindrospira simsi* Mitlehner; and the radiolarian species *Tripodiscinus sengilensis* Kozlova, *T. trilobatus* Kozlova, *T. sibiricus* Kozlova, *Petalospyris foveolata* Ehrenberg, *P. fiscella* Kozlova, etc. Until now, these radiolarian species have not been found in open ocean sediments.

Palaeogeographic issues

During the middle-late Palaeocene, the Middle Volga Region was a shallow-water, highly productive marine basin with siliceous sedimentation. It is obvious that Palaeocene sediments of the Middle Volga Region are accumulated in the great gulf of the epicontinental sea, via an intensive upwelling process. Distanov (1968) supposed that diatomites may be accumulated in marginal parts of palaeodeltas. It is possible also that diatomite accumulation took place only on topographic highs of subbottom relief.

The main peculiarity of the siliceous microplankton assemblages is their provincialism. The taxonomic composition of the associations differs strongly from coeval oceanic assemblages. Deep-sea diatom Palaeocene assemblages, restricted generally to the Southern Hemisphere (Fenner 1991; Fourtanier 1991) differ taxonomically from epicontinental assemblages due to palaeoecological and palaeogeographical differences, and preservation factors. Epicontinental diatom assemblages of the Northern Hemisphere are highly diverse due to high percentages of meroplanktonic species.

Although Palaeocene diatom assemblages from the Southern Hemisphere and Volga Region differ strongly, the presence of common species suggests a connection between these areas of the World Ocean, possibly through the Tethys and East Atlantic. The geography of the connection between Middle Volga Region and West Siberian basins (including the eastern Urals slope), and the North European basins (Fur Formation, Denmark and Sambian Formation, Kaliningrad Region, Russia) with biosilica sedimentation (Strelnikova *et al.* 1978; Fenner 1994; Mitlehner 1996) is not still clear.

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APPENDIX

DIATOMS

Actinoptychus sp.
Aulacodiscus distinguendus Hustedt (1958) – Homann 1991, pl. 7, fig. 4.
Aulacodiscus probabilis A. Schmidt – Homann 1991, pl. 4, figs 3-5 (Fig. 7K).
Aulacodiscus schmidtii Wirt (1886) – *Aulacodiscus septus* A. Schmidt f. *septus* A. Schmidt Strelnikova 1974, pl. 19, figs 1-6, tab. 20, figs 1-5. (Fig. 7F).
Aulacodiscus suspectus A. Schmidt (1876) – Homann 1991: 37, pl. 6, figs 1-5; pl. 7, figs 1-3, 5 [= *Coscinodicus josefinus* Grunow – Strelnikova *et al.* 1978, pl. 15, figs 1, 2] [= *Coscinodiscus uralensis* Jousé – Proshkina-Lavrenko 1949: 73, pl. 24, fig. 4 (Fig. 6K)].

Briggera sibirica (Grunow) Ross & Sims, 1985: 300, pl. 3, figs 1-7. – Homann 1991: 74, pl. 8, Figs 1-11 [= *Biddulphia tuomeyi* (Bailey) Roper var. *tridenta* Jousé – Strelnikova *et al.* 1978, pl. 17, fig. 5 (Fig. 5D)].

Coscinodiscus anissimovae Gleser & Rubina, 1968: 153, pl. 1, figs 1-6. – Proshkina-Lavrenko 1974, pl. 38, fig. 8.
Coscinodiscus sp. Common occurrence of large *Coscinodiscus* is recorded at the Sengiley section. These belong mostly to *Coscinodiscus oculus iridis* Ehrenberg (1839) group, *Coscinodiscus radiatus* Ehrenberg (1839) group, and *Coscinodiscus argus* Ehrenberg (1838).
Costopyxis antiqua (Jousé) Gleser, 1984: 291 [= *Stephanopyxis antiqua* Jousé, 1951: 46, pl. 1, fig. 3. – Strelnikova 1974, pl. 3, figs 18-20].
Craspedodiscus moelleri A. Schmidt (1893) – Proshkina-Lavrenko 1974, pl. 23, fig. 2. – Homann 1991: 47, pl. 17, figs 1-5 (Fig. 6D).
Cylindrospira simsi Mitlehner, 1995: 323, figs 3-6, 9-18 [= *Pyxilla multiseptata* Gleser, 1995, pl. 1, fig. 16 (Fig. 6B)].

Eunotogramma variabile Grunow (1883) – Proshkina-Lavrenko 1974, pl. 15, fig. 12 (Fig. 5E).

Eunotogramma weissii Ehrenberg (1955) – Proshkina-Lavrenko 1974, pl. 5, fig. 6 (Fig. 4A).

Fenestrella antiqua (Grunow) Swatman (1948) – Homann 1991, pl. 18, figs 1, 2, 4, 5.

Grunowiella gemmata (Grunow) Van Heurck (1896) – Fenner 1991, pl. 11, fig. 13 (Fig. 6H).
Grunowiella palaeocaenica Jousé, 1951: 40-41, pl. 4, fig. 5. – Fenner 1991, pl. 11, figs 1-4 (Fig. 6I).

Hemialus ambiguus Grunow (1884) – Fenner 1994, pl. 6, fig. 17 (Fig. 5B, I).
Hemiaulus arcticus var. bornholmensis Cleve-Euler (1951) – Fenner 1994, pl. 8, Figs 1, 2 (Fig. 5F).
Hemiaulus curvatulus Strelnikova, 1971: 49, pl. 1, figs 12, 13. – Harwood 1988, figs 12, 13 (Fig. 5O, S).
Hemiaulus danicus Grunow (1878) – Homann 1991, pl. 20, figs 1-10 (Fig. 5N).
Hemiaulus frigidus (Grunow) Fenner, 1994: 112, pl. 8, fig. 4 (Fig. 5C).
Hemiaulus incisus Hajos, 1976: 829, pl. 23, figs 4-9. – Fenner 1991, pl. 10, fig. 9 (Fig. 5G).
Hemiaulus incurvus Shibkova *in* Krotov & Shibkova, 1959: 124, pl. 4, fig. 8. – Gombos 1977, pl. 16, figs 1-7 (Fig. 5A).
Hemiaulus proteus Heiberg, 1863 – Proshkina-Lavrenko 1974, pl. 19, fig. 3. – Homann 1991, pl. 24, figs 15-18 (Fig. 5P, R).
Hemiaulus cf. rossicus Pantocsek, 1889 – Proshkina-Lavrenko 1974, pl. 15, fig. 10 (Fig. 5L, M).
Hyalodiscus radiatus (O' Meara) Grunow var. ***arctica*** Grunow (1884) – Homann 1991, pl. 26, figs 3, 6-9.

Kentrodiscus fossilis Pantocsek (1889) – Harwood 1988, figs 16-18 [= *Pterotheca* sp. – Homann 1991, pl. 54, figs 7-9 (Fig. 7G)].

Lisitzinia distanovii Gleser, 1995, pl. 1, fig. 5 (Fig. 4C).

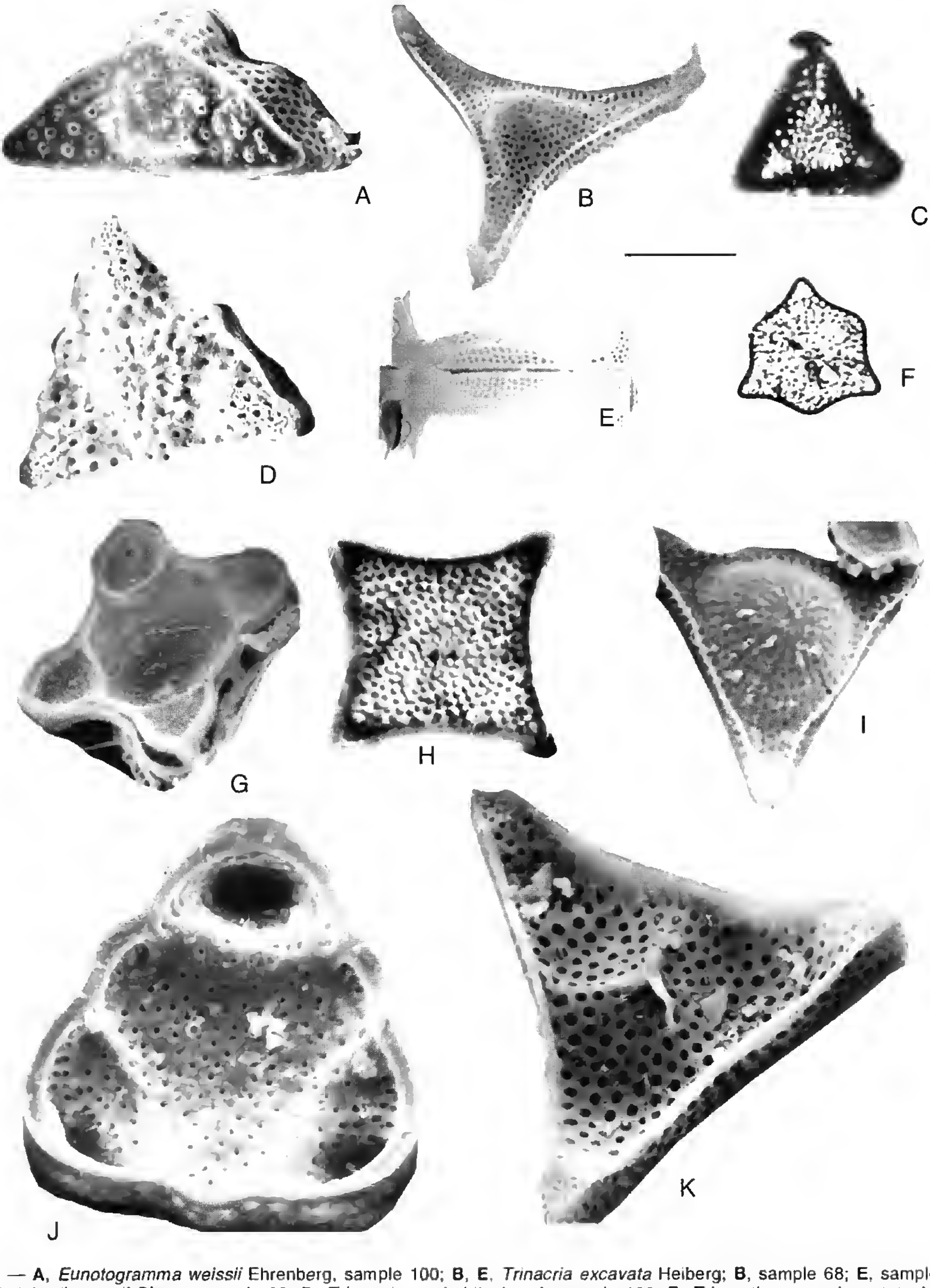

FIG. 4. — **A**, *Eunotogramma weissii* Ehrenberg, sample 100; **B**, **E**, *Trinacria excavata* Heiberg; **B**, sample 68; **E**, sample 58; **C**, *Lisitzinia distanovii* Gleser, sample 69; **D**, *Triceratium mirabile* Jousé, sample 100; **F**, *Triceratium sparsipunctata* Jousé, sample 67; **G**, *Solium exsculptum* Heiberg, sample 58; **H**, *Trinacria regina* Heiberg, sample 61; **I**, *Triceratium ventriculosum* A. S., sample 100; **J**, *Triceratium flos* Ehrenberg, sample 100; **K**, *Triceratium heibergii* Grunow, sample 58. Scale bar: A, B, D, G, I, J, 26.6 µm; C, 13.3 µm; E, 28.5 µm; F, 40 µm; H, 20 µm; K, 23.5 µm.

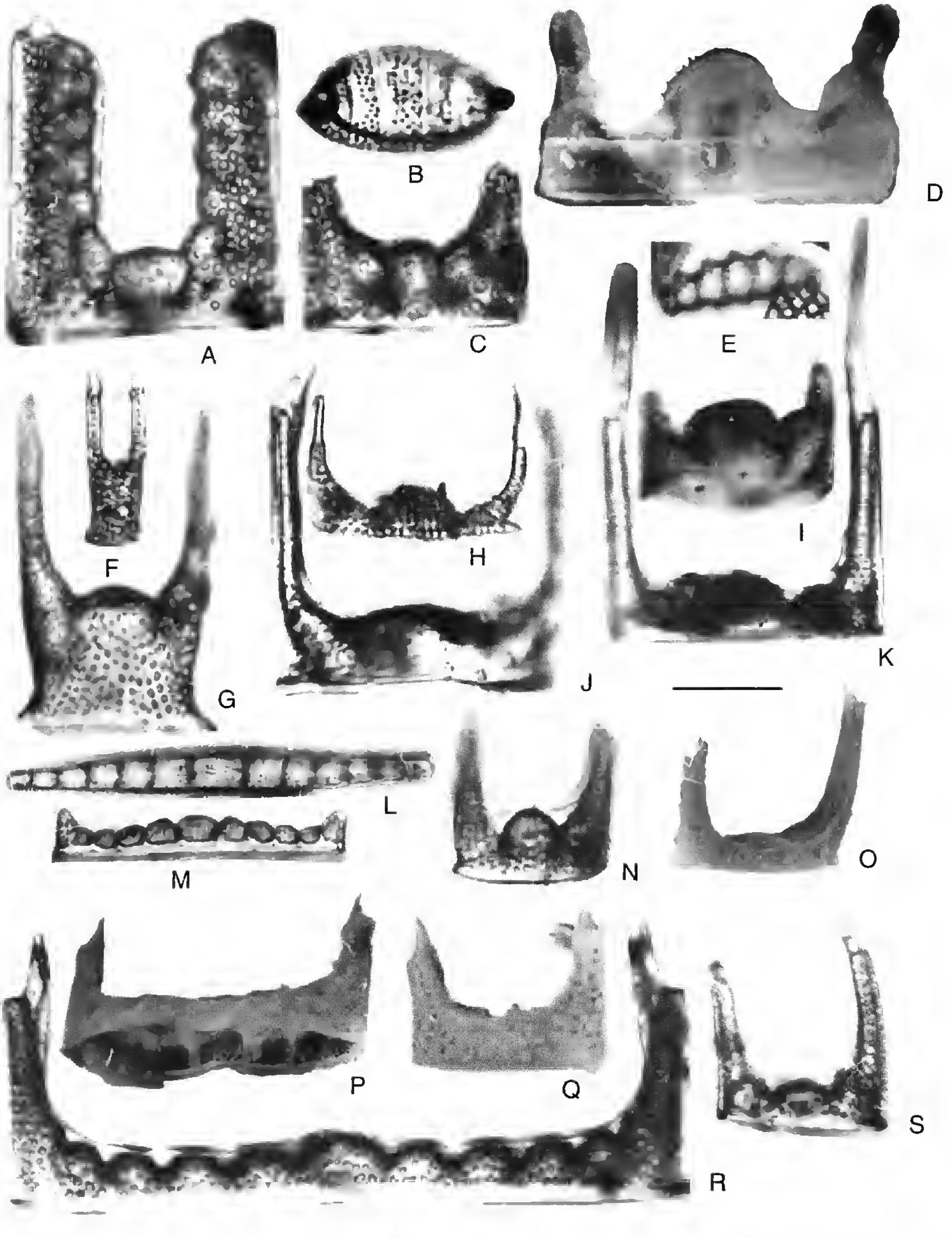

FIG. 5. — **A**, *Hemiaulus incurvus* Shibkova, sample 85; **B**, **I**, *Hemiaulus ambiguus* Grunow, sample 85; **C**, *Hemiaulus frigidus* (Grunow) Fenner, sample 67; **D**, *Briggera sibirica* (Grunow) Ross & Sims, sample 58; **E**, *Eunotogramma variabile* Grunow, sample 88; **F**, *Hemiaulus arcticus* var. *bornholmensis* Cleve-Euler, sample 103; **G**, *Hemiaulus incisus* Hajos, sample 58; **H**, **J**, **K**, *Hemiaulus* sp.; **H**, sample 103; **J**, sample 109; **K**, sample 109; **L**, **M**, *Hemiaulus* cf. *rossicus* Pantocsek, sample 67; **N**, *Hemiaulus danicus* Grunow, sample 88; **O**, **S**, *Hemiaulus curvatulus* Strelnikova; **O**, sample 58; **S**, sample 67; **P**, **R**, *Hemiaulus proteus* Heiberg; **P**, sample 58; **R**, sample 61; **Q**, *Hemiaulus* sp., sample 75. Scale bar: A-C, E-N, R, S, 20 μm; D, O-Q, 26.6 μm.

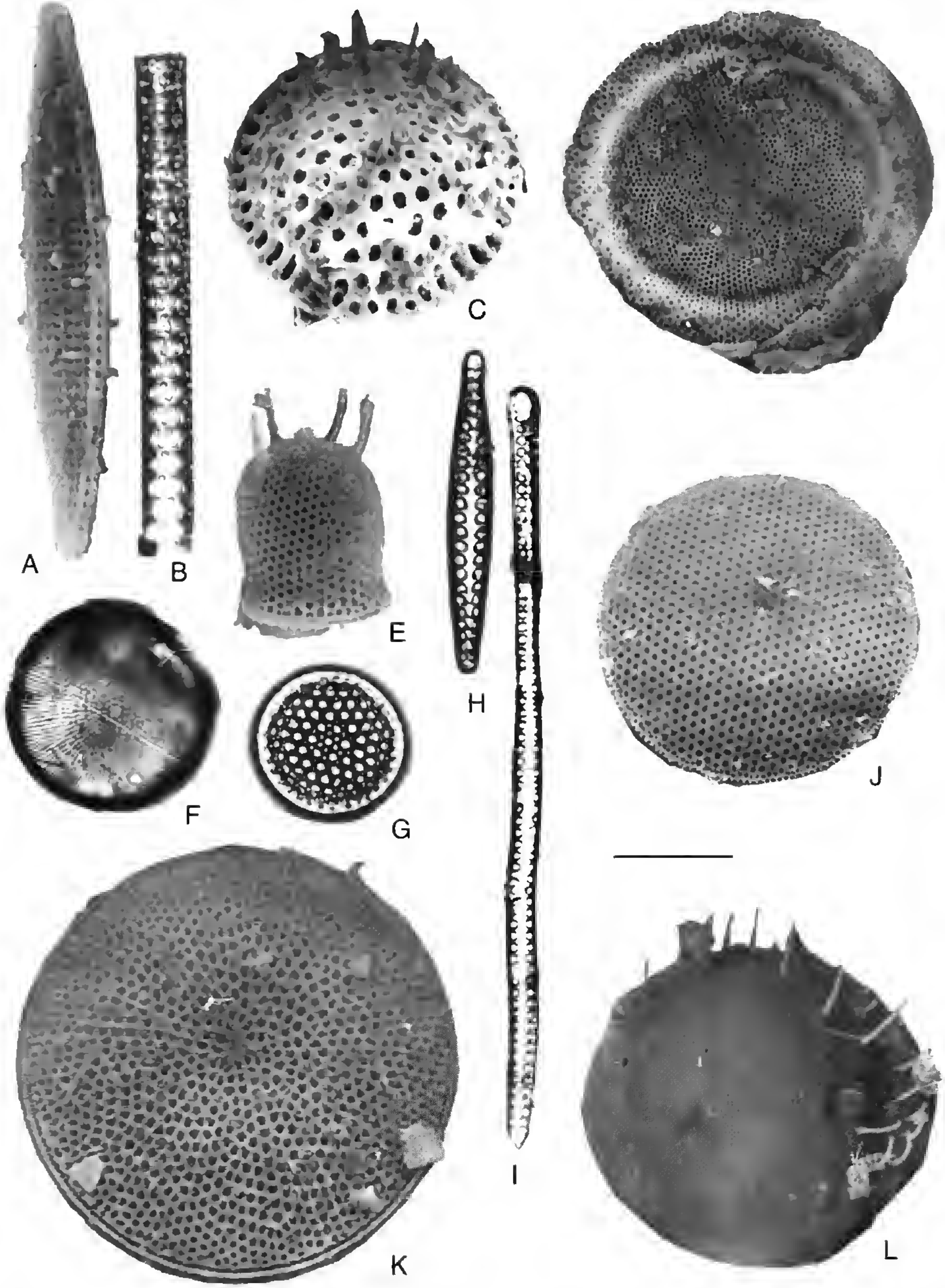

FIG. 6. — **A**, *Rhaphoneis simbirskiana* Grunow & Pantocsek, sample 58; **B**, *Cylindrospira simsi* Mitlehner, sample 67; **C**, *Pyxidicula ferox* (Greville) Strelnikova & Nikolaev, sample 100; **D**, *Craspedodiscus moelleri* A. Schmidt, sample 58; **E**, *Pyxidicula turris* (Greville & Arnott) Strelnikova & Nikolaev, sample 100; **F**, *Thalassiosira* sp. 1 *sensu* Fourtanier, sample 59; **G**, *Pyxidicula* sp., sample 74; **H**, *Grunowiella gemmata* (Grunow) Van Heurk, sample 100; **I**, *Grunowiella palaeocaenica* Jousé, sample 58; **J**, *Thalassiosiropsis wittiana* (Pantocsek) Hasle, sample 100; **K**, *Aulacodiscus suspectus* A. Schmidt, sample 58; **L**, *Pyxidicula* sp., sample 58. Scale bar: A, H, K, 16.6 µm; B, F, G, I, 20 µm; C, 13.3 µm; D, J, 26.6 µm; E, 28.5 µm; L, 25 µm.

Odontotropis carinata Grunow (1884) – Homann 1991, pl. 27, figs 5, 7; pl. 28, figs 1-3 [= *Odontotropis danicus* Debes – Fenner 1985: 734, pl. 14, fig. 11 (Fig. 7I, J).

Odontotropis cristata Grunow (1884) – Homann 1991, pl. 29, figs 1-5.

Paralia crenulata (Grunow) Gleser *stat. nov.* – Makarova 1992: 50, pl. 41, figs 1-8.

Paralia grunowii Gleser *stat. et nom. nov.* – Makarova 1992: 51, pl. 41, figs 9-11; pl. 42.

Paralia sulcata (Ehrenberg) Cleve (1884) – Makarova 1992: 52, pl. 43.

Proboscia cretacea (Hajos & Stradner) Jordan & Priddle, 1991: 56 [= *Rhizosolenia cretacea* Hajos & Stradner, 1975: 929, pl. 7, fig. 1; pl. 31, figs 4-6. – Fenner 1991, pl. 1, figs 4-9].

Pseudopodosira westii (W. Smith) Sheshukova & Gleser, 1964, pl. 1, figs 4, 5.

Pseudopodosira sp. 2 *sensu* Homann, 1991: 134, pl. 54, figs 9, 10.

Pseudostictodiscus angulatus Grunow (1876) – Fenner 1994, pl. 3, figs 12-17 (Fig. 7D).

Pterotheca major Jousé, 1955: 101, pl. 6, fig. 2. – Harwood 1988, figs 16, 18.

Pyxidicula ferox (Greville) Strelnikova & Nikolaev – Makarova 1988: 41, pl. 23, figs 7, 8 (Fig. 6C).

Pyxidicula moelleri (A. Schmidt) Strelnikova & Nikolaev, 1986: 952 [=*Coscinodiscus moelleri* A. Schmidt – Homann 1991, pl. 10, figs 4-8 (Fig. 7A).

Pyxiducula sp. Common occurrence of different *Pyxidicula* is observed in the upper part of Granoe Ukho section. Most of these belongs to *Pyxidicula turris* (Greville & Arnott) Strelnikova & Nikolaev, 1986 group and *Pyxidicula corona* (Ehrenberg) Strelnikova & Nikolaev, 1986 group.

Rattrayella oamaruensis (Grunow) De Toni (1896) – Homann 1991, pl. 33, figs 1-7 (Fig. 7C).

Rattrayella rotundata (Shibkova) Gleser, 1995, pl. 1, fig. 20. (Fig. 7B).

Rhaphoneis morsiana Grunow *in* Pantocsek (1886-89) *em.* Homann 1991: 129, pl. 34, figs 9-12.

Rhaphoneis simbirskiana Grunow *in* Pantocsek (1886-89) – Proshkina-Lavrenko 1974, pl. 15, fig. 15 (Fig. 6A).

Rhizosolenia hebetata Bailey (1856) – Homann 1991, pl. 36, figs 5, 11, 12.

Solium exsculptum Heiberg (1863) – Homann 1991, tf. 37, figs 1, 3, 5-7 [= *Trinacria exsculpta* (Heiberg) Hust. – Mukhina 1976, pl. 2, fig. 7 (Fig. 4G).

Stellarima microtrias (Ehrenberg) Hasle & Sims, 1986: 11, figs 18-27.

Thalassiosira sp. 1 *sensu Thalassiosira* ? sp. 1 *sensu* Fourranier, 1991, pl. 1, fig. 12 [= Genus and specie indet. – Schrader & Fenner 1976, pl. 33, fig. 7 (Fig. 6F)].

Thalassiosiropsis wittiana (Pantocsek) Hasle, Hasle & Syversten, 1985, 89 f, Abb. 1-41. – Homann 1991, pl. 37, figs 8-10 (Fig. 6J).

Triceratium flos Ehrenberg (1885) – Homann 1991, pl. 44, figs 1, 2, 6 (Fig. 4J).

Triceratium heibergii sensu Gombos, 1977, pl. 1, figs 1-12 [= *Triceratium caudatum* Witt, Proshkina-Lavrenko, 1974, pl. 15, fig.] [= *Trinacria muricata* Gleser, 1995, pl. 1, fig. 4 (Fig. 4K)].

Triceratium kinkeri A. Schmidt (1874-1959) – Prosh-kina-Lavrenko 1974, pl. 23, fig. 3.

Triceratium mirabile Jousé *in* Proshkina-Lavrenko, 1949: 166, pl. 6, fig. 5 – Fenner 1991, pl. 9, figs 7-10 (Fig. 4D).

Triceratium sparsipunctata Jousé, *in* Proshkina-Lavrenko 1949: 169, pl. 64, fig. 6 (Fig. 4F).

Trinacria ventriculosa (A. Schmidt) Gleser, *in* Proshkina-Lavrenko 1974, pl. 18, fig. 12 (Fig. 4I).

Trinacria excavata Heiberg (1863) – Homann 1991, pl. 46, figs 1-8; pl. 47, figs 1-6. (Fig. 4B, E).

Trinacria pileolus (Ehrenberg) Grunow (1884) – Gombos 1977, pl. 37, figs 3, 4.

Trinacria regina Heiberg (1863) *em.* Homann 1991: 124, pl. 50, figs 1-7; pl. 51, figs 1-7. – Proshkina-Lavrenko 1974, pl. 23, fig. 6 (Fig. 4H).

Trochosira spinosa Kitton (1871) – Homann 1991, pl. 17, figs 6-13.

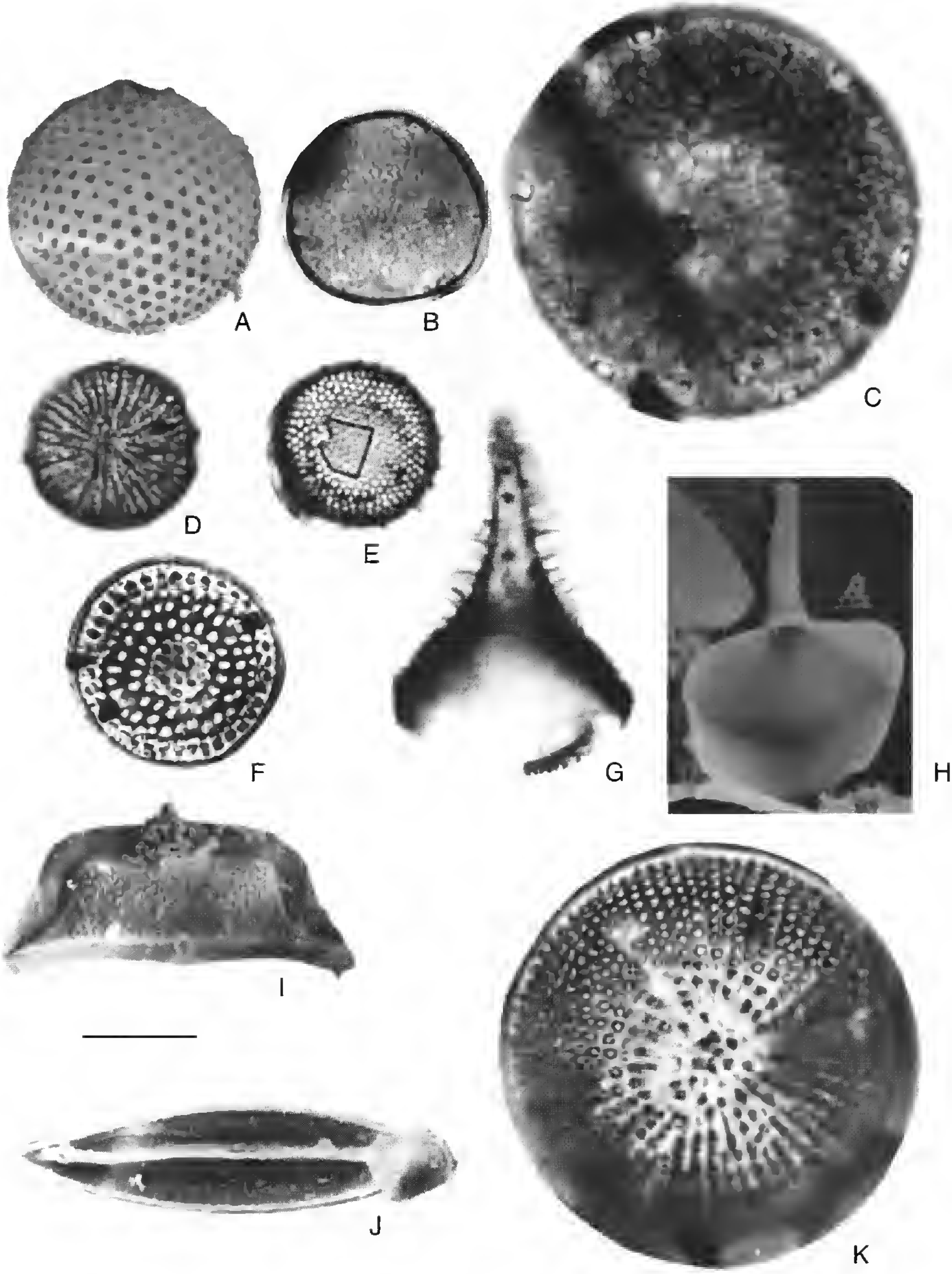

FIG. 7. — **A**, *Pyxidicula moelleri* (A. Schmidt) Strelnikova & Nikolaev, sample 58; **B**, *Rattrayella rotundata* (Shibkova) Gleser, sample 79; **C**, *Rattrayella oamaruensis* (Grunow) De Toni, sample 87; **D**, *Pseudostictodiscus angulatus* Grunow, sample 74; **E**, *Pyxidicula* sp., sample 58; **F**, *Aulacodiscus schmidtii* Witt, sample 74; **G**, *Kentrodiscus fossilis* Pantocsek, sample 94; **H**, *Pterotheca* sp., sample 100; **I**, **J**, *Odontotropis carinata* Grunow, sample 100; **K**, *Aulacodiscus probabilis* A. Schmidt, sample 88. Scale bar: A, 14.2 µm; B-D, G, K, 20 µm; E, 40 µm; F, 13.3 µm; H-J, 26.6 µm.

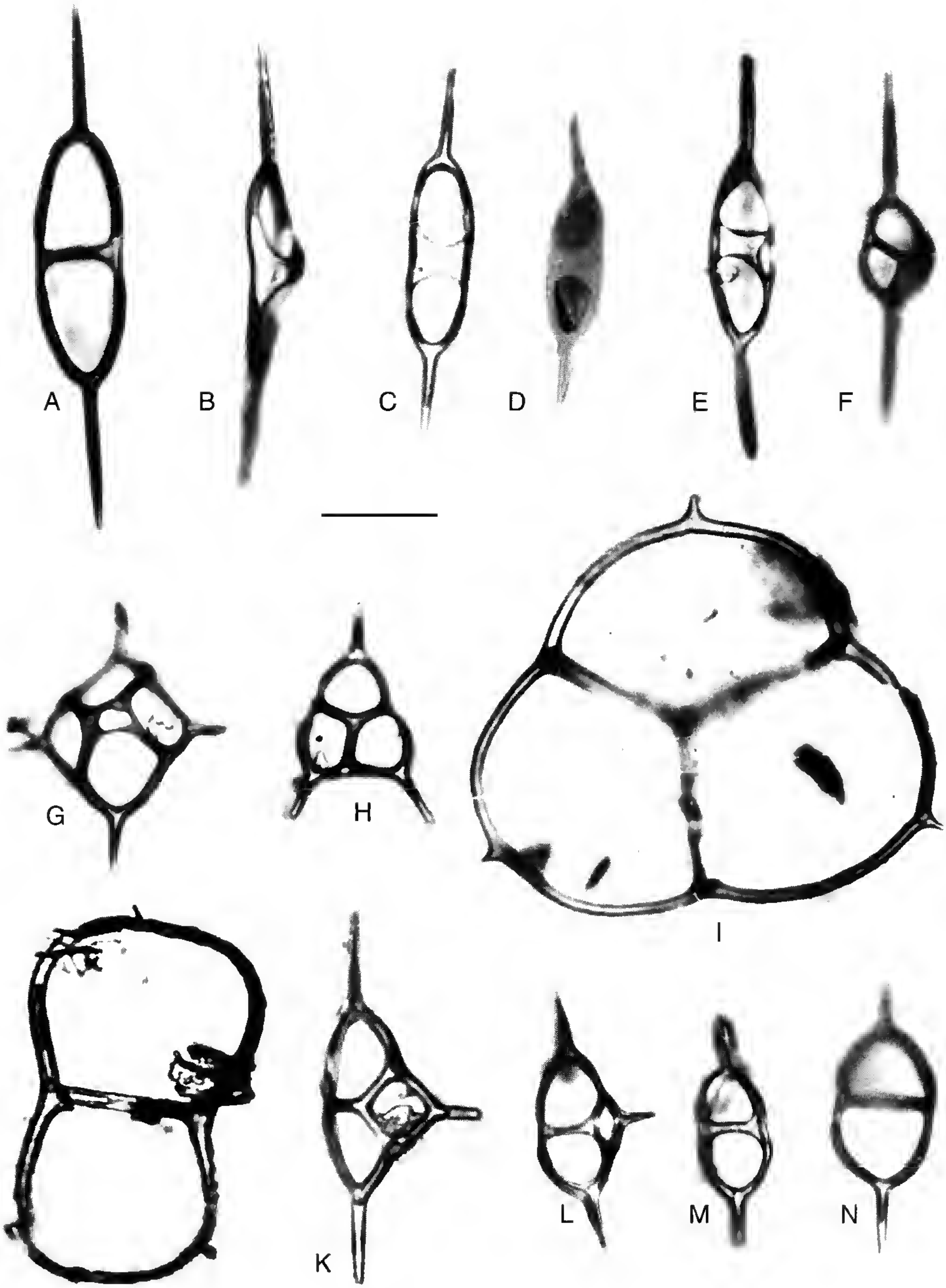

FIG. 8. — **A-D**, *Naviculopsis constricta* (Schulz) Frenguelli; **A**, sample 74; **B**, sample 58; **C**, sample 67; **D**, sample 58; **E**, *Naviculopsis punctilia* Perch-Nielsen, sample 67; **F**, *Naviculopsis danica* Perch-Nielsen, sample 67; **G**, *Dictyocha precarentis* Bukry, sample 88; **H**, *Corbisema hastata hastata* (Lemmermann) Bukry, sample 108; **I**, *Corbisema hastata globulata* Bukry, sample 58; **J**, *Corbisema disymmetrica* var. *communis* Bukry, sample 109; **K**, **L**, *Dictyocha elongata* Gleser; **K**, sample 88; **L**, sample 95; **M**, **N**, *Naviculopsis robusta* Deflandre; **M**, sample 74; **N**, sample 109. Scale bar: A-C, E-N, 20 µm; D, 26.6 µm.

Xanthiopyxis sp. 1-form 7 *sensu* Homann 1991, pl. 57, figs 14, 15.

SILICOFLAGELLATES

Corbisema disymmetrica var. *communis* Bukry, 1976: 891, pl. 1, figs 5-9. – Perch-Nielsen 1985, fig. 11(8) [= *Dictyocha navicula* Ehrenberg, Gleser 1966: 251, pl. 9, figs 4, 5; text-fig. 6(6)] [= *Corbisema naviculoidea* (Frenguelli) Perch-Nielsen, 1976: 33, fig. 7, 19, 22 (Fig. 8J)].
Corbisema hastata hastata (Lemmermann) Bukry, 1976: 892, pl. 4, figs 9-16. – Perch-Nielsen 1985, fig. 11 (22, 23) (Fig. 8H).
Corbisema hastata globulata Bukry, 1976: 892, pl. 4, figs 7, 8 (Fig. 8I).
Corbisema inermis inermis (Lemmermann) Bukry, 1976: 892, pl. 5, figs 1-3.

Dictyocha elongata Gleser, 1960: 131, 132, tabl. 1, pl. 2, figs 16-20. – Perch-Nielsen 1976, fig. 2 (Fig. 8K, L).
Dictyocha fibula Ehrenberg (1839) – Perch-Nielsen 1985, fig. 15 (17).
Dictyocha precarentis Bukry, 1976: 894, pl. 6, figs 6-13; pl. 7, figs 1-3 (Fig. 8G).

Naviculopsis constricta (Schulz) Frenguelli, (1940) – Perch-Nielsen 1985, figs 26 (6, 7) (Fig. 8A-D).
Naviculopsis danica Perch-Nielsen, 1976: 35, figs 5, 6, 21. – Gleser 1995, pl. 1, fig. 27 (Fig. 8F).
Naviculopsis punctilia Perch-Nielsen, 1976: 36, figs 26, 27; 1985, fig. 26 (33) (Fig. 8E).
Naviculopsis robusta Deflandre (1950) – Gleser 1995, pl. 1, fig. 29 (Fig. 8M, N).

RADIOLARIA

Anthocyrtoma (?) frizzeli Nishimura, 1992: 332, pl. 9, fig. 13, 14; pl. 13, fig. 8.

Botryometra (?) osha Kozlova, 1978: 95, 96, pl. VI, fig. 9, 10; pl. XIX, fig. 3.

Buryella tetradica Foreman, 1973: 443, 8, figs 4, 5; pl. 9, figs 13, 14. – Kozlova 1984, pl. XII, fig. 16 [= *Lithocampium* sp. A – Riedel & Sanfilippo 1971, pl. 7, fig. 12].

Clathrocyclas elegans (Lipman, 1958) – Kozlova 1978, pl. 17, figs 1, 4, 5. – Kozlova 1990: 78, pl. XII, fig. 14. – Petrushevskaya & Kozlova 1979, fig. 500 [= *Theocorys sporta* Kozlova *in* Kozlova, Gorbovetz 1966: 11, pl. 17, fig. 8.
Clathrocyclas extensa Clark & Campbell, 1942: 85, pl. 8, fig. 11. – Bjorklund 1977, pl. 21, fig. 4. – Kozlova & Gorbovetz 1966, pl. 21, fig. 8. – Petrushevskaya & Kozlova 1979: 131, fig. 38b, 504.
Clathrocyclas lipmanae Kozlova, 1978: 121, pl. 6, fig. 3, 6, pl. 17, fig. 12, pl. 19, fig. 8. – Kozlova 1990: 78, pl. XII, fig. 21.
Clathrocyclas longispina Clark & Campbell, 1942 – Kozlova 1978, pl. XVII.

Diplocyclas cornuta runjevae Kozlova, 1978: 124, pl. VI, fig. 1 ,4, pl. XIX, fig. 6.
Diplocyclas pseudobicorona pseudobicorona Nishimura, 1992: 340, pl. 4, figs 4-6, pl. 13, fig. 14.

Larnacalpis (?) smili Middour-Kozlova 1978, pl. IX, figs 3, 5.
Lophophaena curta Kozlova, 1978, pl. V, figs 7, 8; pl. XIX, fig. 4.

Peritiviator (?) dumitricae Nishimura, 1992: 328, pl. 1, fig. 13-16, pl. 11, figs 11, 12.
Petalospyris fiscella (Kozlova) – *Tetraspyris fiscella* Kozlova *in* Kozlova & Gorbovetz 1966: 92, tabl. XV, fig. 1 [= *Hexaspyris* sp. – Petrushevskaya & Kozlova 1972, pl. 40, fig. 6] [= *Hexaspyris fiscella* (Kozlova) – Kozlova 1978: 89, pl. VIII, fig. 6].
Petalospyris foveolata Ehrenberg & Kozlova, 1978: 89-90, pl. 6, fig. 8; pl. 8, fig. 10; pl. 19, figs 9-13.
Petalospyris tumidula Kozlova *in* Kozlova & Gorbovetz, 1966: 97, pl. XV, figs 10, 11.
Phormocyrtis reticula (Kozlova) [= *Theocorys reticula* Kozlova *in* Kozlova & Gorbovetz, 1966: 110, pl. XVII, fig. 7].
Plectodiscus totchilinae Kozlova, 1984: 206-207, pl. X, fig. 13.

Spongasteriscus cruciferus Clark & Campbell, 1942 – Kozlova 1984, pl. X, fig. 16.
Spongodiscus americanus Kozlova *in* Kozlova & Gorbovetz, 1966, tabl. XIV, figs 1, 2. – Sanfilippo & Riedel 1973: 524, pl. 27, fig. 11; pl. 28, fig. 9 [= *Spongodiscus americanus americanus* Kozlova, 1978: 77, tabl. XIV, fig. 3].
Spongomelissa numa callosa Kozlova, 1978: 101, pl. XII, fig. 2; pl. XIX, fig. 2.
Spongomelissa numa numa Kozlova, 1978: 100, 101, pl. XII, figs 4, 5.
Spongomelissa (?) ternaria Kozlova, 1978: 101, 102, pl. VIII, fig. 1; pl. XIX, fig. 1.
Spongotrochus alveatus Riedel & Sanfilippo *in* Sanfilippo & Riedel, 1973: 525, pl. 13, figs 4, 5; pl. 30, figs 3, 4. – Kozlova 1984, pl. XI, fig. 6.
Spongotrochus helioides (Cleve) – [= *Spongotrochus* sp. *aff. Trochodiscus helioides* Cleve – Kozlova 1978: 82, 83, pl. 16, fig. 6].
Spongotrochus nativus praecox Kozlova, 1978: 78, pl. 14, fig. 1.
Spongotrochus paciferus antiquus Kozlova, 1978, tabl. XVI, figs 4, 5.
Spongotrochus puter Kozlova, 1978: 82, pl. 5, fig. 10.

Thecosphaerella rotunda Borissenko, 1960: 222, pl. 1, fig. 3, pl. 3, figs 2, 3. – Sanfilippo & Riedel 1973: 522, pl. 26, fig. 3 [= *Thecosphaera melitomma* Kozlova *in* Kozlova & Gorbovetz 1966: 52, pl. VII, figs 7, 8].
Tripodiscinus sengilensis Kozlova, 1978: 104, 105, pl. V, figs 1-5; 1984: 207, 208, pl. XII, 20.
Tripodiscinus sibiricus Kozlova, 1978: 103, 104, pl. XII, fig. 3; 1984: 208, pl. XII, fig. 4 [= ***Tripodiscinus tumulosa*** (Kozlova) – Petrushevskaya 1971, figs 33-V-VI] [= *Tripodiscinum* sp. A – Petrushevskaya 1971, figs XI-XII].
Tripodiscinus trilobatus Kozlova, 1978, pl. X, figs 4, 5.

Eocene stratigraphy of key sections of the Dnieper-Donets Depression based on calcareous and siliceous microplankton

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ABSTRACT

Radiolarian, diatom, nannoplankton, and foraminifer assemblages were studied in detail in four key sections (Kantemirovka, Sergeevka, and 9540 Rudaevka, 5-93 Boguchar boreholes) of the south and central parts of the Voronezh anticline area. The widespread middle Eocene sediments lie uncorformably on marls and limestones of Upper Cretaceous age. They are mainly composed by a transgressive-regressive succession of phosphoritic sands, marls, and siliceous clays of the Kiev Formation in the Ukraine (or Sergeevka and Tishki formations in Russia) and by sandy clays and siliceous clays of the lower part of the Khar'kov Formation in the Ukraine (or Kas'anovka Formation in Russia). Lithologically, the coeval formations range from terrigenous-carbonate to siliceous-carbonate. The age of the formations has long remained a point of discussion. Recent studies based on calcareous and, especially, siliceous microplankton allowed a direct correlation of these sections with standard zonal scales.

KEY WORDS
Dnieper-Donets Depression, radiolaria, diatoms, silicoflagellates, foraminifera, Eocene, stratigraphy.

RÉSUMÉ

Stratigraphie des coupes clés de l'Éocène dans la dépression du Dniepr-Donets fondée sur le microplancton calcaire et siliceux.

Les assemblages de radiolaires, diatomées, nannoplancton et foraminifères ont été étudiés en détail dans quatre séries clés (les coupes de Kantemirovka et Sergeevka et les forages 9540 Rudaevka et 5-93 Boguchar) des parties méridionale et centrale de la région de l'anticlinal de Voronezh. Les sédiments, largement répandus, de l'Éocène moyen reposent en discontinuité sur des marnes et calcaires du Crétacé supérieur. Ils sont principalement composés d'une succession transgression-régression de sables phosphatés, de marnes et d'argiles siliceuses de la formation de Kiev en Ukraine (ou les formations de Sergeevka et Tishki en Russie) et par des argiles sableuses et des argiles siliceuses dans la partie inférieure de la formation de Khar'kov en Ukraine (ou de Kas'anovka en Russie). Lithologiquement, les formations équivalentes vont des carbonates terrigènes aux carbonates siliceux. L'âge des formations est resté longtemps très discuté. Les études récentes, fondées sur le microplancton calcaire et surtout siliceux permettent des corrélations directes avec les zones des échelles standart.

MOTS CLÉS
Dépression du Dniepr-Donets, radiolaires, diatomées, silicoflagellés, foraminifères, Éocène, stratigraphie.

INTRODUCTION

The Palaeogene sediments of the south-eastern slope of the Voronezh anticline, which also represents the north-east flank of the Dnieper-Donets Depression (see Radionova *et al.*, this volume, fig. 1), have been studied stratigraphically since the 1960s, when the lithostratigraphic scheme was proposed and used to subdivide these deposits (Semenov 1965). The Palaeogene deposits of the region represent a gradual transition from typical facies of the Dnieper-Donets Basin (Ukrainian type of succession) to facies of the Volga-Don Region. In the western part of the area, a Ukrainian lithostratigraphic scheme (Makarenko *et al.* 1987) is used. The Palaeogene of the marginal east-northern areas of Dnieper-Donets Basin is subdivided according to Semenov (1965). In Volga-Don Region, the scheme of Kurlaev (1968) is used (Fig. 1). This facies transition can be observed in sections studied in the present paper. The presence of both calcareous and siliceous microplankton in all studied sections allowed us to correlate the Eocene part of all the sections.

The Palaeogene succession of the western Kantemirovka and Sergeevka sections (Fig. 2) is very similar to that of the central part of Dnieper-Donets Depression and begins with dark green and greyish green mica-glauconite sands of Buchack Formation containing no macro- or microfossils. Up to the section lies the Sergeevka Formation represented by marls with sandy and clayey interlayers at the base. The superposing Tishki Formation is composed by sandy noncarbonate clays. Both Sergeevka and Tishki formations represent distinct transgressive-regressive cycle and are believed to correspond to the Kiev Formation of the Ukraine. The overlapping Kas'yan Formation, as a rule, begins with sandy layer grading up to the section into siliceous clays. The uppermost Kantemirovka Formation is exposed in the Kantemirovka Section only and is composed of sandy deposits. The Kas'yan and Kantemirovka formations represent the second transgressive-regressive cycle and are coeval to the Khar'kov Formation of the Ukraine.

In the Boguchar Section, the Eocene formations are composed of facies different from that of the three western sections (Sergeevka, Kantemirovka and Rudaevka). The lowermost sedimentary cycle includes lowermost Osinovo and Tchir beds, represented by more terrigenous sediments

<table>
<tr><th colspan="2">Epoch</th><th>Stages</th><th colspan="2">Dnieper-Donets Depression (Makarenko *et al.* 1987)</th><th>South-eastern border of Voronezh antecline (Semionov 1965)</th><th>Lower reaches of Volga and Don rivers (Kurtaev & Akhlestina 1988)</th><th colspan="2">This paper</th></tr>
<tr><td>Oligocene</td><td></td><td></td><td rowspan="2">Kharkov Formation</td><td>Mezhigorka Fm.</td><td>Kantemirovka Fm.</td><td></td><td rowspan="2">Kante-mirovka Fm.</td><td rowspan="3">Kharkov Fm.</td></tr>
<tr><td rowspan="5">Eocene</td><td>Upper</td><td>Priabonian</td><td>Obukhovka Fm.</td><td>Kasyan Fm.</td><td></td></tr>
<tr><td rowspan="4">Middle</td><td rowspan="2">Bartonian</td><td colspan="2" rowspan="3">Kiev Fm.</td><td rowspan="2">Tishki Fm.</td><td rowspan="2">Kuma Fm.</td><td>Kasyan Fm.</td></tr>
<tr><td>Tishki Fm.</td><td rowspan="3">Kiev Fm.</td></tr>
<tr><td rowspan="2">Lutetian</td><td>Sergeevska Fm.</td><td>Tchir beds</td><td rowspan="2">Sergeevka Fm.</td></tr>
<tr><td colspan="2"></td><td>Osinovo Fm.</td><td>Osinovo Fm.</td></tr>
</table>

FIG. 1. — The Eocene lithostratigraphic scheme of the studied region.

than those of Sergeevka Formation, and brownish clays named Kuma Formation. The last formation corresponds in its sedimentary composition and stratigraphic position to the Kuma Formation of rhe Northern Cis-Caucasia.

Lithostratigraphical units of south-western Russia (Voronezh anticline) can be considered as a reflection of the transgressive-regressive succession in the North Peri-Tethys Region. A number of problems arise when the issues concerning the Palaeogene palaeogeography and detailed age correlation are to be approached.

The first problem is the age span of the Kiev "marl" and its correlation with eastern sections. The second problem lies in determining the age of the siliceous units, i.e., the upper part of the Kiev Formation and the lower part of Khar'kov Formation, and in correlating them with coeval stratigraphic units further east.

SAMPLES

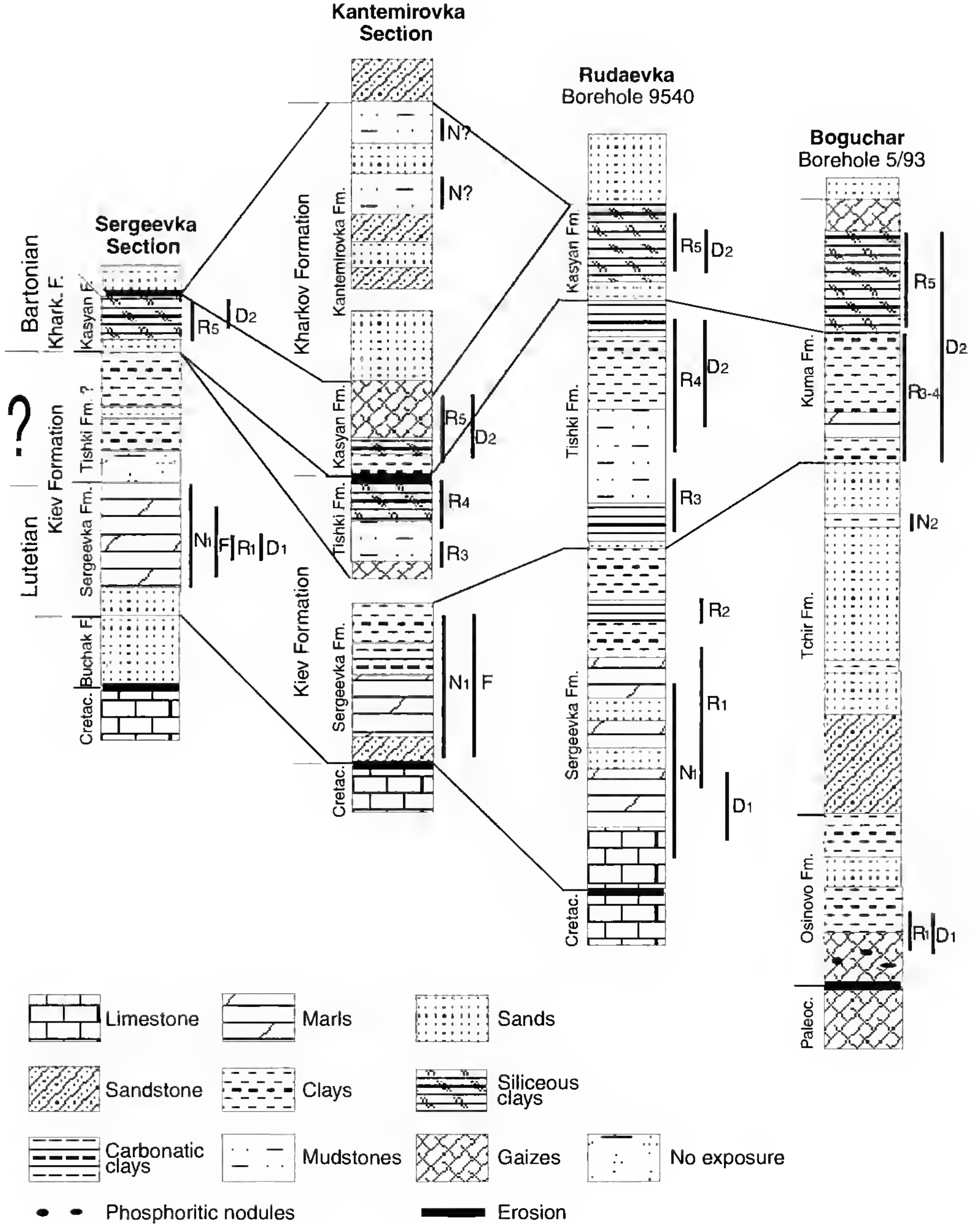
Two sections – Kantemirovka and Sergeevka – and two boreholes – 5-93 Boguchar and 9540 Rudaevka – were sampled carefully during the field trip to the Voronezh anticline area in July 1994. More than 100 samples were processed, and in 79 of them microfossils were found (Fig. 2A).

METHODS

To study siliceous micro-organisms, each sample was placed into a 400 ml glass, desegregated mechanically, and then boiled for 15 minutes with addition of about 50 ml of 30% hydrogen peroxide (H_2O_2). Each sample was soaked for one hour with distilled water, rinsed, and the procedure was repeated until the settling time became about 5 minutes for radiolarians. Slides for radiolarian study were prepared on 24 × 24 mm cover glasses and mounted in Canada balm on 24 × 80 mm glass slides. Samples for diatom study were mounted on 18 × 18 glass slides. Radiolarians were examined at × 400, and diatoms, at × 1000.

For nannoplankton study, smear slides from liquid alcohol suspension were made with Canada balm and examined at × 1000 with the use of immersion oil.

A


Kantemirovka Section
Rudaevka Borehole 9540
Boguchar Borehole 5/93
Sergeevka Section
Bartonian
Lutetian
Khark. F.
Kiev Formation
Kharkov Formation
Kantemirovka Fm.
Kasyan Fm.
Tishki Fm.
Sergeevka Fm.
Buchak F.
Cretac.
Kuma Fm.
Tchir Fm.
Osinovo Fm.
Paleoc.
Limestone
Marls
Sands
Sandstone
Clays
Siliceous clays
Carbonatic clays
Mudstones
Gaizes
No exposure
Phosphoritic nodules
Erosion

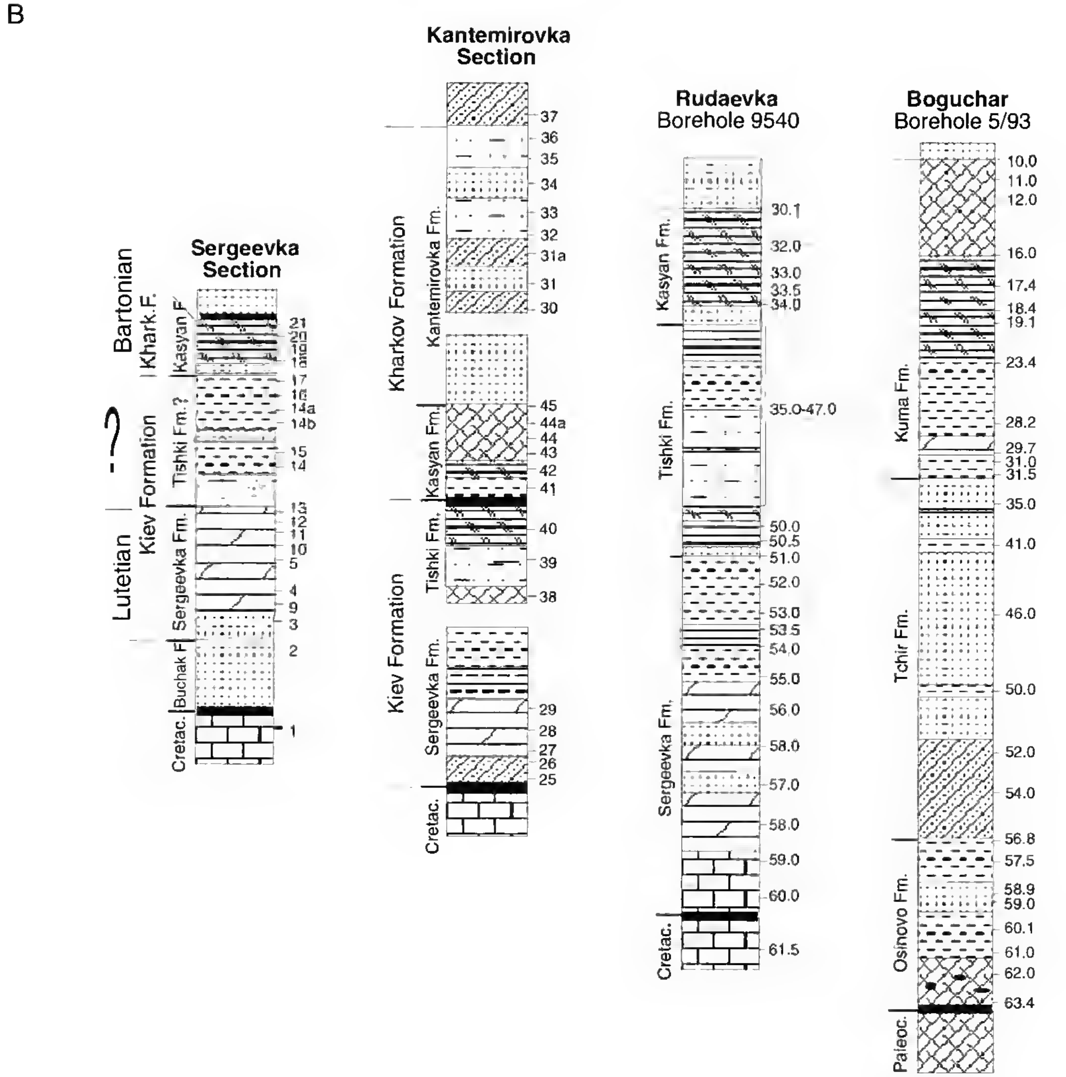


FIG. 2. — **A**, correlation of studied sections of the eastern slope of the Dnieper-Donets Depression. $\mathbf{N}_{1\text{-}2}$, nannofossil assemblage; **F**, foraminifera assemblage; $\mathbf{R}_{1\text{-}5}$, radiolaria assemblage; $\mathbf{D}_{1\text{-}2}$, diatoms assemblage. **B**, samples number from the sections.

Foraminifers were washed with the use of sieves and examined at × 25-30.

MICROPALEONTOLOGICAL ANALYSIS

The correlation of the foraminifera, nannofossil, silicoflagellate, radiolaria, and diatom zonal scales used in this paper are shown in Figure 3. Results of micropalaeontological study of sections are shown in Figures 2, 3 and Tables 1 to 13. Species were recorded as abundant (A) if more than 15 specimens were present in the slide, as frequent (F) if 10-15 species were present, as common (C) if 3-9 specimens occurred in the slide, and as rare (R) if 1-2 specimens were found.

SERGEEVKA SECTION

Sergeevka Section, occupying the north-western-

most position among the studied sections, is very similar in lithological composition to the succession of the Dnieper-Donets Depression. It begins with dark green and greyish green mica-glauconite sands of the Buchack Formation, which are barren of macro- and microfossils. Up to the section, the Kiev Formation represented by marls with sandy and clayey beds 7 m in thickness lies. These are overlain by the Kiev Formation: marls with sandy and clay beds 7 m thick. The upper part of the Kiev Formation is composed of sandy non-carbonate clays, 5 m in thickness. The lower part of the formation is the same as the Sergeevka Formation of Semenov (1965) scheme, and the upper part of the Kiev Formation is equivalent to Semenov (1965) Tishki Formation. The lower part of the Khar'kov Formation [Kas'yan Formation of Semenov (1965) scheme] begins with sandy layer passing upsection into siliceous clays. The exposed thickness of these sediments is about 5 m. They are unconformably overlapped by sands of Neogene (?) age.

Nannofossils
At the base of the Sergeevka Formation in a sandy unit, a poor nannofossil assemblage (N: range of nannofossil assemblage in Figs 2, 3) of the middle Eocene age is present.
A rather abundant nannofossil association (N1) including *Cyclicargolithus floridanus* (Roth & Hay *in* Hay *et al.* 1967) Bukry, *Discoaster barbadiensis* Tan, *D. nodifer* (Bramlete & Riedel) Bukry, *D. strictus* Stradner, *D. wemmelensis* Achuthan & Stradner, *Reticulofenestra dictyoda* (Deflandre *in* Deflandre & Fert), Stradner *in* Strander & Edwards, etc, was found in marls of the Sergeevka Formation (Table 1). Nevertheless, the absence of any boundary zonal markers does not allow us to judge whether it belongs to the uppermost CP13 *Nannotetrina quadrata* or lowermost CP14 *Reticulofenestra umbilica* zones.

Foraminifera
In the marls of the Sergeevka Formation, an abundant and well-preserved benthic foraminifera association (F: range of foraminifera assemblage in Figs 2, 3) contains *Spiroplectammina pishvanovae* A. V. Furssenko & K. B. Furssenko, *Clavulinoides sczaboi* (Hantken), *Vaginulinopsis decorata* (Reuss), *Cibicidoides biumbonatus* (A. V. Furssenko & K. B. Furssenko), *Uvigerina spinocostata* Cushman & Jarvis (= *Hopkinsia bykovae ukrainica* Kraeva), *U. costellata* Morozova, *Bulimina macilenta* Cushman & Parker, *B. cooki* Cushman (Table 2). This assemblage can be related to the middle-upper Lutetian *Pseudoclavulina subbotinae-Uvigerina spinocostata-Bolivina cookei* regional zone (Naidin *et al.* 1994; Radionova *et al.* 1994).

Radiolaria
The most ancient radiolarian assemblage (R: range of radiolarian assemblage in Figs 2, 3) was found in the middle part of the marls of the Sergeevka Formation (Table 3) and is represented by *Clathrocyclas minima* Clark & Campbell, *Heliodiscus heliasteriscus* Clark & Campbell, *H. dupla* Kozlova, *Spongomelissa* sp. A, *Lithomelissa* sp. A, *Calocyclas semipolita* Clark & Campbell, *Thecosphaera minor* Campbell & Clark, *Stylotrochus radiatus* Lipman, *Theocyrtis lithos* Clark & Campbell. Taxonomical composition of the association cannot constrain the age of sediments more precisely than middle Eocene. Upsection, radiolaria are found only in siliceous clays of Kas'yanovka Formation assemblage (R5) is taxonomically diversified and abundant, containing *Stylodictya irregularis* Vinassa, *Heliodiscus heliasteriscus* Clark & Campbell, *Heterosestrum formosum* Tochilina, *H. tschuenkoi* Lipman, *Lithomelissa* sp. B, *Melittosphaera magnoporulosa* Nakaseko, *Heliodiscus fragilis* Tochilina, *H. testatus* Kozlova, *"Lophocyrtis" sinitzini* Lipman, *Clathrocyclas extensa multiplicata* (Clark & Campbell), *Tripodiscinus kaptarenkoi* Gorbunov, *T.* aff. *tribrachiatus* Gorbunov, *Theocyrtis lithos* Clark & Campbell, and *Theocyrtis andriashevi* Petrushevskaya. It belongs to the *Theocyrtis andriashevi* regional zone.

Diatoms
In the lower part of the Sergeevka Formation (Table 4), a typical Kiev diatom assemblage with *Peponia barbadensis* Greville (D1) (D: range of diatom assemblage in Figs 2, 3) was found. Common taxa include *Paralia oamaruensis* (Grove & Stuart) Gleser – index-species of the zone of the same name of the local scheme of

Epoch		Stage	Planktonic foraminifera zonation (Boli & Saunders 1985)	Crimea-Caucasus planktonic foraminifera zonal scale (Anonymous 1989)	Nannofossil zonal scale (Okada & Bukry 1980)	Silicoflagellate zonal scale (Bukry 1981)	Regional zonal scales: radiolarians (Kozlova 1990)	Regional zonal scales: diatoms Glezer 1989	Regional zonal scales: diatoms this paper
EOCENE	upper		P15	*Globigerapsis tropicalis*	CP15 *Chiasmolithus oamaruensis*	*Corbisema apiculata*	*Theocyrtis andriasheva* R5	*Paralia oamaruensis*	
	middle	BARTONIAN	P14	*Globigerina turkmenica*	CP14b *Discoaster saipanensis*	*Dictyocha hexacantha*	*Ethmosphara polysiphonia* R4		layers with *Brightwellia imperfecta* D2-D2A
			P13	*Hantkenina alabamensis*	CP14a *Discoaster bifax*		*Cytophormis alta* R3		
		LUTETIAN	P12	*Acarinina rotundimarginata*	CP13 *Nannotetrina quadrata*	*Naviculopsis foliaceae*	*Heliodiscus quadratus* R2	*Pyxilla oligocenica* var. *tenue*	layers with *Peponia barbadensis* D1

FIG. 3. — The correlation of the foraminifera, nannofossil, silicoflagellate, radiolaria and diatom zonal scales.

Glezer (1979) – and *Cristodiscus* (*Coscinodiscus*) *succinctus* (Sheshukova & Gleser) Gleser & Olshtinskaya, dare index-species of the boreal zonal scheme of Strelnikova (1992). *Peponia barbadensis* Greville, index-species of the proposed regional scheme (Radionova 1996) occurs rarely. According to Glezer's (1979) local diatom scheme, the *Paralia oamaruensis* zone is related to the Upper Eocene, and according to Strelnikova (1992) boreal scheme, the *Coscinodiscus succinctus* zone belongs to uppermost Lutetian-lower Bartonian. Layers with *Peponia barbadense* Greville are considered as upper Lutetian. The association includes pelagic species *Pyxidicula joynsonii* (A. Schmidt) Strelnikova & Nikolaev, *P. charkoviana* (Jousé) Strelnikova & Nikolaev, *Craspedodiscus moelleri* A. Schmidt, and a number of neritic species. In Khar'kov (Kas'yanovka) Formation, a diatom assemblage with *Brigthwellia imperfecta* Jousé (D2) becomes more abundant. Besides, *Melosira architecturalis* Brun (Schmidt *et al.*) and *Pyxilla prolongata* Brun are common. The *Coscinodiscus* group becomes more diversified (*C. decrescenoides* Jousé, *C. bulliens* Schmidt, *C. oculusiridis* Ehrenberg), as well as the *Hemiaulus* group (*H. polymorphus* var. *charkovianus* Jousé, *H. tschestnovii* Pantoäek). In the upper part of the Brighwellia imperfecta (?) unit, *Cosmiodiscus breviradiatus* Gleser & Olshtinskaya and *Pseudotriceratium chenevieri* (Meisrner) Gleser, appear. Index-species *Brightwellia imperfecta* Jousé, covering a part of the Bartonian stratigraphic interval of distribution, allows determining the stratigraphic range of the Kas'yanovka Formation.

KANTEMIROVKA SECTION

The lower part of Sergeevka Formation (Fig. 2), a sandstone layer 1.5 m thick with phosphorite nodules, lies on the Upper Cretaceous limestones. Up to the section is a unit of grey marls and carbonate clays 3-4 m thick. The upper part of the Sergeevka Formation is represented by non-carbonate clays of undetermined thickness. The Tishki Formation lies unconformably on the Sergeevka Formation and is composed of non-carbonare clays 4-5 m thick, with glauconite at the base and siliceous in the upper part. The Kas'yanovka Formation is represented by intercalations of reddish-yellowish gaize, breccia-like argilites, and glauconite sandstones 4 m thick. Sands and sandstones of the Kantemirovka Formarion overlap these sediments unconformably.

Nannofossils

An abundant and diversified nannofossil assemblage was obtained from the marls of the Sergeevka Formation (N1) (Fig. 2). This assemblage includes, among others, the typical species of the CP13 *Nannotetrina quadrata* zone: *Nannotetrina cristata* (Martini) Perch-Nielsen, *Discoaster strictus* Stradner, *Dictyococcites onustus* Perch-Nielsen (Table 5).

In the uppermost part of the section, i.e. in carbonate beds within the sandy Kantemirovka Formation, a very poor and possibly reworked nannofossil assemblage of Bartonian age was found.

Foraminifera
In the lower part of the Sergeevka Formation marls, the abundant and diversified plankronic foraminifera assemblage (F) was found (Table 6). The most abundant are: *Subbotina turcmenica* (Khalilov), *S. boweri* (Bolli), *Globigerinatheka index* (Finlay), *Acarinina* aff. *rugosoaculeata* Subbotina. The assemblage can be related to the upper part of the *Acarinina rotundimarginata* (s.l.) zone of the Crimea-Caucasus scheme (beds with *Globigerinatheka index*, Beniamovskii 1995). Benthic foraminifera are represented by *Pseudoclavulina subbotinae* Nikitina, *Vaginulinopsis decorata* (Reuss), *Gyroidina soldani* (d'Orbigny), *Bulimina sculptilis* Cushman, *B. cooki* Cushman, *Uvigerina spinocostata* Cushman & Jarvis, *U. pygmea* d'Orbigny, *U. costellata* Morozova. They are related to the middle-late Lutetian *Pseudoclavulina subbotinae-Uvigerina spinocostata-Bolivina cookei* regional zone. Most of the species of the assemblages can be traced in the European palaeobiogeographical area from Belgium to the west part of Kazakhstan.

Radiolaria
In the lower part of the Tishki Formation, the radiolarian assemblage (R3) is taxonomically poor, represented by *Cyrtophormis alta* Moksyakova, *Clathrocyclas talwanii* Bjotklund & Kellogg, and *Lithomelissa* sp. A. (Table 7) and most likely belongs to the *Cyrtophormis alta* regional zone (Kozlova 1990).
Upsection in uppermost part of the Tishki Formation and lowermost part of the Kas'yanovka Formation (the boundary between them is not determined precisely in the section), radiolaria become more diversified (R4): *Lithomelissa* sp. A., *Heliodiscus heliasteriscus* Clark & Campbell, *H. zonatum* (Lipman), *H. fragilis* Tochilina, *Melittosphaera magnoporulosa* Nakaseko, *Calocyclas semipolita* Clark & Campbell, *Tripodiscinus kaptarenkoe* Gorbunov, *Clathrocyclas extensa multiplicata* (Clark & Campbell), *"Lophocyrtis" sinitzini* Lipman, *Bathropyramis aneotos* (Clark & Cambell), *Calocyclas asperum* Ehrenberg, *Hexacontium* aff. *pachydermum* Jorgensen, *Stylodyctya hastata* Ehrenberg, *S. irregularis* (Vinassa), *Tripilidium clavipes* Bjorklund, *Theocyrtis lithos* Clatk & Campbell, etc. Lastly, in siliceous clayey marls of the Kas'yanovka Formation, the assemblage of *Theocyrtis andriashevi* regional zone (R5) is seen and includes besides a number of species known from R4 assemblage, *Lithelius foremanae* Sanfilippo & Riedel, *Stylosphaera balbis* (Sanfilippo & Riedel), *Lithomelissa* sp. B, *Heterosestrum formosum* Tochilina, *H. tschuenkoi* Lipman, and *Theocyrtis andriashevi* Petrushevskaya.

Diatoms and Silicoflagellates
The diatom assemblage obtained from the upper part of the Tishki and Kas'yanovka formations is similar to the D2 association from the Sergeevka Section, although it is not so diversified (Table 8). Important is the presence of *Cosmiodiscusm breviradiatus* Gleser & Olshtinskaya, and *Brightwellia coronata* (Brightwell) Ralfs *in* Pritchard, in the lower Kas'yanovka Formation and the appearance of *Triceratium unguiculatum* Greville, in the upper part of the same formation.

9540 Rudaevka borehole
White chalk unit 3 m in thickness is correlated to the Sergeevka Formation (Fig. 2). It is superseded by alternating marls and carbonate clays 6 m thick. The upper part of the Sergeevka Formation is composed of alternating carbonate and non-carbonate clays The total thickness of the Sergeevka Formation is 13 m. At the base of the Tishki Formation, a layer of glauconite sand up to 0.5 m thick can be traced. The overlying unit is represented by intercalations of clayey mudstones, opoka sandstones and clays, sometimes with thin beds of carbonate clays. The thickness of this formation is 14 m. At the base of the Kas'yanovka Formation, a 0.5 m-thick glauconite sandy layer is present, overlapped by clayey diatomites 4 m in thickness. The uppermost 8 m of the section are represented by sands of the Poltava Formation.

Nannofossils
A nannofossil assemblage related to CP13-CP14 nannoplankton zones boundary interval (N) was found at the base of the marly section of the Sergeevka Formation. The assemblage is not so rich as in Kantemirovka Section, but seems to be of the same age because of the presence of *Rhabdosphaera gladius* Locker, which is zonal marker of the CP13 *Nannotetrina quadrata* zone top boundary (Table 9).

Foraminifera
Foraminifera in borehole 9540 occur rarely. For this reason, siliceous microfossils are the primary basis for stratigraphic subdivision of the section.

Radiolaria
A radiolarian assemblage (Table 10) represented by *Stylodyctya hastata* Ehrenberg, *Thecosphaera minor* (Clark & Campbell), *Heliodiscus heliasteriscus* Clark & Campbell, *Clathrocyclas principi principi* Clark & Campbell, *Stylotrochus* sp., and *Lithomelissa* sp. A was found in the lower part of the Sergeevka Formation marls. The assemblage is not taxonomically diversified. All the species are known from the Keresta and Kuma formations of southern Cis-Caucasia and Central Asia (Moksyakova 1972). The age cannot be constrained more precisely than upper Luthetian-Bartonian. The upper part of the same formation contains a more diversified assemblage (R2), represented by *Heliodiscus hexasteriscus* Clark & Campbell, *Hexacontium pachydermum* Jorgensen, *Petalospyris* aff. *dubia* Clark & Campbell, *Clathrocyclas extensa* Clark & Campbell, *Theocorys reticula* Kozlova, *Heterosestrum formosum* Tochilina, *H. tschuenkoi* Lipman, *Stylosphaera coronata laevis* Ehrenberg, *Tripodiscinus tumulosus* (Kozlova), *Xiphospira occllata* (Ehrenberg), *Thecosphaera californica* Clark & Campbell and *Lithomelissa* aff. *haeckeli* Butschli. The composition of the association is close to the Kuma Formation, the assemblage not including only species of the genera *Tripodiscinus* and *Heterosestrum*.
Up to the section in clayey marls of the Tishki Formation, an assemblage containing abundant *Cenosphaera mitgarzi* Lipman and rare *Heterosestrum tschuenkoi* Lipman, *Peripyramis circumtexta* Haeckel, and *Cyrtophormis alta* Moksyakova was found. The presence of the latter species together with *Heterosestrum tschuenkoi* Lipman, in spite of the poor taxonomical composition allows correlating this association to the *Cyrtophormis alta* (R3) regional radiolarian zone. Higher up to the section in clays of the same formation, the following radiolarian assemblage (R4) is present: *Cenosphaera mitgarzi* Lipman, *Stylodyctya irregularis* (Vinassa), *S. hastata* Ehrenberg, *Heterosestrum formosum* Tochilina and *Theocorys reticula* Kozlova. These taxa are not indicative but the stratigraphical position of the assemblage in the section suggests that it can be related approximately to the *Ethmosphaera polysiphonia* regional zone.
Up to the section in siliceous clays of the Kas'yanovka Formation, the radiolarian assemblage (R5) becomes more diversified and abundant: *Cenosphaera micropora*, *Stylodyctya irregularis* (Vinassa), *S. hastata* (Ehrenberg), *Heliodiscus zonatus* Tochilina, *Heterosestrum formosum* Tochilina, *Lithelius* sp., *Theocyrtis andriashevi* Petrushevskaya, *Calocyclas semipolita* Clark & Campbell and *Lithomelissa* sp. B. This assemblage most probably belongs to the *Theocyrtis andriashevi* regional zone.

Diatoms and Silicoflagellates
Diatoms were found at the base of the marl unit of the Sergeevka Formation and in noncarbonate clays in the upper part of the same Formation. The assemblage is rather poor (D1) (Table 11). Besides, species known from the Kantemirovka and Sergeevka sections; *Cristodiscus duplex* Gleser & Olshtinskaya and *Coscinodiscus* aff. *tenerrimus* Jousé, and silicoflagellates *Dictyocha pentagona* (Schulz) Bukry & Foster, and *Naviculopsis foliaceae* Deflandre can be noted. In the lower part of Tishki Formation, a poor diatom assemblage containing neritic *Paralia sulcata* (Ehrenberg) Cleve, *Pseudopodosira hyalina* Jousé and *Aulacodiscus excavatus* A. Schmidt was found. Among pelagic species, *Coscinodiscus obscurus* var. *cancavus* Gleser *in* Diatomovye vodorosly SSSR, dominates. In the upper part of the Tishki Formation, the diatom flora becomes more diversified. More representatives of the *Pyxidicula* genus [*P. moelleri* (A. Schmidt)

Strelnikova & Nikolaev, *P. grunowii* (Grove & Stuart) Strelnikova & Nikolaev, *P. joynsonii* (A. Schmidt) Strelnikova & Nikolaev, *P. charkoviana* (Jousé), Strelnikova & Nikolaev), *Craspedodiscus oblongus* (Greville) Hanna and *Coscinodiscus* aff. *marginatus* Ehrenberg] appear. Large diatom cells dominate along with unusually looking specimens of *Melosira architecturalis* Brun (Schmidt *et al.*) which are up to 60-70 mm in diameter. The disappearance of *Craspedodiscus oblongus* (Greville) Hanna takes place in the upper part of the Bartonian. The presence of this typical species determines the age of the upper part of the Tishki Formation as the Bartonian.
The assemblage of the Kas'yanovka Formation includes common species of D2 assemblage. In the uppermost part of the formation (depth 32 m), the abundance and diversity of silicoflagellates increases. Common are typical Bartonian taxa such as *Naviculopsis folinceae* Deflandre, *N. nordica* Bukry, *Distephanus crus* (Ehrenberg) Haeckel, *Dictyocha spinosa* (Deflandre) Glezer, *D. deflandrei* Franguelli, *Corbisema hastata globulata* Bukry, *C. inermis* Lemm.

5-93 Boguchar borehole
The lithostratigraphic subdivision of this section is made according to the scheme of Kurlaev & Akhlestina (1988) for the Khoper monocline. The Veshenka Formation (Fig. 2), composed by sandy opokas 5 m thick, lies on the Upper Cretaceous sediments. The Osinovo beds overlie them unconformably. They are represented by light grey opokas with phosphorite nodules at the base, intercalated with sandstones. Their thickness is 6 m. The Tchirsky beds consist of strong quartzites 5.2 m thick, and upsection of fine-grained glauconite sands with rare beds of calcareous clays. Their thickness is 18 m. The Kuma Formation lies on sands and is represented by greenish low-carbonate opokas 2 m thick, turning up to the section into brownish non-calcareous clays. The upper part of the formation is composed by light opokas passing into opoka sandstones. The total thickness of the formation is 20 m.

Nannofossils
The rather poor nannofossil assemblage with rare *Chiasmolithus grandis* (Bramlette & Riedel) Radomski, *C. modestus* Perch-Nielsen, *C. solitus* (Bramlette & Sullivan) Locker, *Discoaster barbadiensis* Tan, *D. nodifer* (Bramletter & Riedel) Bukry, *Neococcolithus dubius* (Deflandre) Black, *Reticulofenestra dictyoda* (Deflandre *in* Deflandre & Fert) Stradner *in* Stradner & Edwards, *R. umbilicus* (Levin) Martini & Ritzkovski, *Coccolithus formosus* (Kamptner) Wise found in siliceous marls within a sandy unit formerly considered as a part of Buchack (?) Formation, but this association can be considered as the uppermost part of the Lutetian CP13 *Nannotetrina quadrata* zone or the lowermost Bartonian CP14a *Discoaster bifax* subzone.

Radiolaria
A radiolarian assemblage (Table 12) obtained from the base of Osinovo beds contains *Clathrocyclas minima* Lipman, *Heliodiscus heliasteriscus* Clark & Campbell, *H. dupla* Kozlova, *Spongomelissa* sp. A, *Lithomelissa* sp. A, *Thecosphaera minor* Campbell & Clark, *Spongotrochus radiatus* Lipman, *Stylodyctya irregularis* (Vinassa), and *Theocyrtis lithos* Campbell & Clark. The age of the assemblage is tentatively thought to be the middle Eocene, and not younger than upper Lutetian.
Up to the section in siliceous clays and marls of Kuma Formation, the abundant radiolarian assemblages of the *Cyrtophormis alta*-*Ethmosphaera polysiphonia* (R3-R4) regional zones were found. The association contains *Hexacontium pachydermum* Jorgensen, *Stylosphaera coronata coronata* Ehrenberg, *Lithelius spiralis* Lipman, *Bathropyramis anoetus* (Clark & Campbell), *Clathrocyclas talwanii* Bjorklund & Kellogg, *Cenosphaera mitgarzi* Lipman, *Theocyrtis lithos* Clark & Campbell, *Cyrtophormis alta* Moksyakova, *Artobotrys norvegiensis* Bjorklund & Kellogg, *Theocorys reticula* Kozlova, *Lithomelissa stigi* Butschli, *Tripodiscinus tribrachiatus* Kozlova, *T. kaptarenkoi* Gorbunov, and several other taxa.
The youngest radiolarian assemblage of the *Theocyrtis andriashevi* regional zone (R5) was obtained from siliceous clays of Kuma Formation. It is abundant, well-preserved, and contains *Hexacontium pachydermum* Kozlova, *Heterosestrum shabalkini* Lipman, *Thecosphaera minor* Campbell & Clark, *Tripodiscinus tribra-*

chiatus Kozlova, *Theocyrtis andriashevi* Petrushevskaya, *Haliomma immensa* Kozlova, *Calocyclas asperum* Ehrenberg and *Rhodospyris donensis* Zagorodnuk.

Diatoms and silicoflagellates

At the base of the Osinovo beds the following diatom association was found: *Paralia oamaruensis* (Grove & Stuart) Gleser, *Cristodiscus* (*Coscinidiscus*) *succinctus* (Sheshukova & Gleser) Gleser & Olshtinskaya, *Hemiaulus polymorphus* var. *charkovianus* (Sheshukova & Gleser) Gleser & Olshtinskaya, plus *Coscinodiscus obsurcus* var. *concavus* Gleser *in* Diatomovye vodorosly SSSR, *C. asteroides* Truan & Witt, *C. bulliens* A. Schmidt, *C. decrescenoides* Jousé, *C. oculusiridis* Ehrenberg, *Brightwellia* sp., *Hemiaulus polycystinorum* Ehrenberg, *Melosira* Brun (Schmidt *et al.*), *Pyxidicula* aff. *moelleri* A. Schmidt and *P. charkoviana* (Jousé). Silicoflagellates are represented by *Naviculopsis nordica hyalina* Bukry, *Mesocena concava* Perch-Nielsen, *M. apiculata* Schulz and *Dictyocha venzoi* Morlotti & Rio. Key species of this assemblage are the same as those of the D1 association of the three other sections. The association belongs to the upper Lutetian.

In the lower part of Kuma Formation the diatom association (Table 13) is similar to the D2 assemblage from 9540 Rudaevka borehole, and in the middle part of the Kuma Formation the same silicoflagellate assemblage was found. The trend of changes in diatom and silicoflagellate composition is similar both in the 9540 Rudaevka borehole and in the 5-93 Boguchar borehole. At the 17.8 m level silicoflagellates dominate, but upsection they are replaced by siliceous sponges.

Discussion

In the eastern part of Dnieper-Donets Depression (the area of transition to Volga-Don Region) the facies change of Eocene sediments is so dramatic that one needs to use three different lithostratigraphic schemes (Fig. 1) from north-west to south-east to subdivide the Eocene deposits. These schemes (for Ukraine, Voronezh anteclise, and the Volga-Don Region) are not sufficiently correlated yet. In the eastern part of study region, some lithostratigraphic subdivisions of the northern Caucasus scheme are used. That gives us a reason to suggest a lithostratigraphic and microplanktonic correlation for the Crimea-Caucasus area and the Dnieper-Donets Depression, because all the studied sections showed similar sedimentary cyclicities, and their formations can be dated and correlated on the basis of calcareous microfossils in the lower part of sections and on siliceous microfossils in the upper part.

In the Crimea-Caucasus area, the lower middle Eocene (Lutetian) sediments are represented by marls and limestones of Keresta Formation. Up to the section, Kuma Formation composed by carbonatic clays rich in organic matter lies with erosion in a number of localities. The following changes in calcareous microplankton assemblages occur through the Keresta-Kuma boundary. The nannofossil assemblages of Keresta Formation are very rich all over the area, and the CP13 *Nannotetrina quadrata* zone (Fig. 3) and all three subzones (CP13a, CP13b, and CP13c) of nannofossil standard zonal scale (Okada & Bukry 1980) can be established. The top of Keresta Formation is marked by disappearance of *Nannotetrina quadrata* (Bramlette & Sullivan) Bukry, *N. cristata* (Martini) Perch-Nielen (1971), *Discoaster gemmifer* Stradner, *D. martinii* Stradner. No new species appear at the base of Kuma Formation. The CP14 *Reticulofenestra umbilica* zone stands out among the deep ocean sediments owing to the *Discoaster bifax* Bukry appearance. In all studied sections of the South of the Former USSR, this species appears within CP13b *Chiasmolithus gigas* subzone, i.e., much earlier than in DSDP sites, where the zonal scale of Okada & Bukry (1980) was established. Recently, its appearance was recorded within Lutetian deposits of Parisian Basin and Hampshire (Aubri 1983). Hence, this species cannot be used as a zonal marker in epicontinental basins. A few meters above the Kuma Formation's bottom, characteristic species of CP14 zone gradually appear. These changes in nannofossil assemblages led us to place the CP13/CP14 zone boundary along the Keresta-Kuma boundary because in spite of the absence of the traditional zonal marker, these zones are distinguished by the full spectrum of the assemblage.

The changes in planktonic foraminifera assemblages proceed in a similar way. At the top of

Keresta Formation, such peculiar species as *Subbotina frontosa* Subbotina, *S. subtriloculinoides* (Khalilov), *Acarinina bullbrooki* Bolli, *Globigerinatheka subconglobata* (Khalilov *in* Shutzkaya), *G. index* (Finlay) (*Acarinina rotundimarginata* zone of the Crimea-Caucasus zonal scale are present – beds with *G. subconglobata-G. index*). The furaminiferal assemblage of Kuma Formation is composed by *Hantkenina alabamensis* Cushman, *Subbotina aserbaidjanica* (Khalilov) and other species. Then, the *Acarinina rotundimarginata-Hantkenina alabamensis* zone boundary is established mostly by the disappearance of the characteristic species of the first zone and corresponds with Keresta-Kuma formations boundary.

Far to the north, the Kuma Formation sediments onlap the sediments corresponding to the Keresta Formation with pronounced erosion. The siliceous plankton comes into play along with the calcareous microfossils. The correlation of radiolarian and diatom zonal scales with that of foraminifera and nannofossils were made in the sections of the northern Peri-Caspian (Khokhlova 1996; Radionova 1996). The correspondence of the radiolarian *Heliodiscus quadratus* zone (R2) to the foraminiferal *Acarinina rotundimarginata* zone, and *Cytophormis alta* (R3), *Ethmosphaera polysiphonia* (R4) to the foraminiferal *Hantkenina alabamensis* and *Globorotalia turcmenica* zones is shown.

In all studied sections of Dnieper-Donets Depression the same zonal succession was traced. The *Heliodiscus quadratus* (R2) zone assemblage is recorded within the lowermost part of all four sections, i.e., within Sergeevka Formation and Tchir beds. The following three zones (R3-R5) are established within the uppermost part of Tishki and Kas'yan formations. This suggests a correlation of these formations with Kuma Formation of the South of the Former USSR.

It is common knowledge that diatom assemblage of the Kiev and Khar'kov formations of Ukraine was proposed as *Paralia oamaruensis* zone (Glezer *et al.* 1965), but boundary markers were not represented, so that even nowadays under closer examination it is hard to establish the boundaries of this zone. In all studied sections two intervals with abundant diatoms separated by sediment interval of variable thickness without diatoms were found. Hence, we record not zones, but layers with *Peponia barbadensis* Greville (D1) and layers with *Brightwellia imperfecta* Jousé (or *Cosmodiscus brevimdiatus* Gleser & Olshtinskaya) (D2). Beds with *Peponia barbadense* Greville, corresponding to the "Kiev" Formation or its correlates, correlate with the upper Lutherian, and beds with *Brightwellia imperfecta* Jousé, corresponding to the lower part of the "Khar'kov" Formation, with the Bartonian. Of the diatoms, *Peponia barbadensis* Greville is restricted to the Luthetian, *Craspedodiscus oblongus* (Greville) Hanna disappears in the upper part of the Bartonian (Fenner 1985), and *Brightwellia imperfecta* is restricted to the second half of the middle Eocene (Fenner 1985). Silicoflagellates manifest the disappearance of *Dictyocha spinosa* (Deflandre) Gleser (in the Sergeevka Formation) and appearance of *Dictyocha hexacantha* Schulz (in the Kas'yanovka Formation), or else, *Naviculopsis foliacea*/*Dictyocha hexacantha* zone boundary correlates with the CP13/CP14 (Bukry 1981) nannoplankton zone boundary.

PALAEOGEOGRAPHY

The benthic forams *Pseudoclavulina subbotinae* Nikitina, *Uvigerina spinocostata* Cushman & Jarvis, *Vaginulopsis decorata* (Reuss), *Clavulinoides szaboi* (Hantken), *Bulimina macilenta* Cushman & Parker, *Bolivina cooki* Cushman, *Spiroplectamina pishvanovae* A. V. Furssenko & K. B. Furssenko in the Sergeevka Section are widespread in Lutetian deposits of various Peri-Tethys localities from Belgium to West Turkmenia (Kaasschniter 1961; Furssenko & Furssenko 1961; Shutzkaya 1970; Bugrova 1988; Grigaylis *et al.* 1988; Naidin *et al.* 1994). The fact that the same foraminifera assemblage is spread over an enormous area in the northern Peri-Tethys suggests the existence of a continuous basin with ubiquitous palaeobiologic links. Moving along the line of sections studied in the present paper from north-west to south-east, i.e., from Sergeevka Section to the Boguchar borehole, it can be seen that radiolarian assemblages are more taxonomically diversi-

fied and well-preserved in Boguchar borehole located in the south-eastern part of the region. By the way, taxonomical composition of the earliest complex at the base of section is close to coeval associations of Kuma Formation of southern regions, and that of younger R3-R5 assemblages is similar to coeval complexes of Norway Basin and Peri-Caspian Basin (Kozlova & Petrushevskaya 1979; Khokhlova 1996). Nevertheless, radiolarians in this section represent an association of an open marine basin with normal salinity. Conversely, radiolarian composition in borehole 9540 seems to reflect alternating open marine and of shallow-water basin conditions, possibly with a restricted connection with the main basin. Sediments at the base of section (Sergeevka marls) and in the upper part of the section (Kas'yanovka siliceous clays, R5) contain diversified open-marine radiolarian associations, but in the middle part of the section in clays of the Tishki Formation, the radiolarian assemblage (R3-R4) is represented by abundant specimens of *Cenosphaera mitgarzi* Lipman and sparse specimens of *Cyrtophormis alta* Moksyakova and *Bathropyramis* sp. A strong predominance of one species is known to testify to the absence of open-oceanic conditions, probably to low salinity conditions.

The oldest radiolarian assemblage is most abundant and diversified in the marls of Sergeevka Formation in the section of the same name, and the youngest (R5) assemblage is most diversified in Kas'yanovka Formation of Kantemirovka Section.

CONCLUSION

The study of four sections of the eastern slope of the Dnieper-Donets Depression allowed us to correct age determination of the Eocene Formation.

The marls of Sergeevka Formation most likely belong to uppermost Lutetian. The benthic foraminiferal zone *Pseudoclavulina subbotinae-Uvigerina spinocostata-Bolivina cookei* distinguished here can be traced in the Keresta Formation through much of the south of European Russia, and in Vemmel and Ash formations of Belgium (Kaasschiter 1961; Radionova *et al.* 1994). The upper part of the planktonic foraminiferal *Acarinina rotundimarginata* zone (bed with *Globigerinatheka index*) found in the lower Sergeevka marls confirms this age determination. Data based on nannofossils (CP13 *Nannotetrina* zone) identify the boundary between their Lutetian age, too.

The age of the Tishki Formation is clearly Bartonian. This interpretation is confirmed by planktonic foraminifera of the *Globigerina turcmenica* zone. The diatom assemblages from the base of the Sergeevka Formation and the lower part of the Osinovo beds (D1), in the upper part of the Tishki, Kas'yanovka and Kuma Formations (D2) are related to *Paralia oamaruensis* diatom zone of (Glezer 1979) and to *Coscinodiscus succinctus* zone of Strelnikova (1992) scheme. In Sergeevka Section, in assemblage D1 the index species *Peponia barbadensis* Greville (Radionova 1996), and in D2, the index species *Brightwellia imperfecta* Jousé, which undoubtedly testify to middle Eocene age, were found.

Sediments of the Kas'yanovka Formation in all studied sections contain almost the same diatom assemblage. A notable feature of the assemblage is the presence of *Paralia oamaruensis* (Grove & Stuart) Gleser and *Coscinodiscus succinctus* (Sheshukova & Gleser) Gleser & Olshtinskaya, the index-species of zones in local diatom schemes of Glezer (1979) and Strelnikova (1992). This diatom assemblage is very close to the association obtained from the base of the Khar'kov Formation in the northern part of Dnieper-Donets Depression (see Radionova *et al.*, this volume, Fig. 1, boreholes 3 and 4; Radionova *et al.* 1994). No evidence of the upper Eocene age for the Kas'yan Formation has been found from radiolaria or diatoms, and we confidently suggest the upper Bartonian age for Kas'yan Formation.

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APPENDIX

TABLE 1. — Stratigraphic range chart of nannofossils in Sergeevka Section. **A**, abundant (more than 15 specimens); **F**, frequent (10-15 specimens); **C**, common (3-9 specimens); **R**, rare (1-2 specimens).

Species/sample number	**8**	**11**	**12**	**14**
Blackites spinosus	F	R		
Chiasmolithus solitus	R	A	C	
Coccolithus formosus	A	C	R	
Cyclicargolithus floridanus	A	A	A	R
Discoaster barbadiensis	F	F	F	
Discoaster binodosus	F	F	F	
Discoaster distinctus	F			
Discoaster nodifer	F	F		
Discoaster saipanensis		F		
Discoaster strictus	R	F		
Discoaster wemmelensis			F	
Helicosphaera bramlettei	F			
Helicosphaera lophata			F	
Holodiscolithus macroporus			F	
Neococcolithes dubius	F	F	F	
Pontosphaera multipora	F	F	F	
Reticulofenestra dictyoda	C	F		F
Reticulofenestra haqii	A	A	C	F
Reticulofenestra umbilicus	A	A	C	
Sphenolithus furcatolitoides	F			
Sphenolithus moriformis	F	F	F	
Sphenolithus spiniger	F	F		
Transversopontis pulcher	F	F	F	F

TABLE 2. — Stratigraphic range chart of foraminifera of Sergeevka Section. **b**, benthos; **p**, plankton. Legend: see Table 1.

Species/sample number		**1**	**2**	**3**	**9**	**4**	**5**	**10**	**11**	**12**	**13**
Acarinina bullbrooki	p		F								
Acarinina pentacamerata	p		A	R							
Acarinina cf. *rotundimarginata*	p		R								
Clavulina cylindrica	b		R		F	F	F	R	F	C	F
Clavulinoides szaboi	b			C		A	R	C	C	C	F
Pseudoclavulina subbotinae	b					R		R	R		F
Spiroplectammina pishvanovae	b				F	F					
Vaginulinopsis decorata	b			C			F	A		F	F
Uvigerina costulata	b						C		C		
Uvigerina macilenta	b			C		C			A		F
Uvigerina spinocostata	b			C						C	

TABLE 3. — Stratigraphic range chart of radiolaria in Sergeevka Section. Legend: see Table 1.

Species/sample number	9	19	20	21	22	23
Calocyclas semipolita	A	R	R		R	
Clathrocyclas minima	C					
Clathrocyclas extensa					A	
Heliodiscus dupla	R					
Heterosesrum formosum			R	F	F	F
Heliodiscus heliasteriscus			C		A	
Heliodiscus zonatus	C					
Heliodiscus fragilis					R	
Heterosestrum tschuenkoi		R			C	
Hexacontium pachydermum		R	R			
Larcospira minor	R					
Lithomelissa sp. B					A	
Lithomelissa sp. A	C	R				
Lophocyrtis sinitzini		C	R			
Melittosphaera magnoporulosa					C	
Phacodiscus testatus					C	
Porodiscus parvus					R	
Spongomelissa sp. A	C					
Stylodyctya irregularis	R		C		C	
Stylotrochus radiatus	R					
Theocyrtis lithos	C	F			R	
Thecosphaera californica			R			
Tripodiscinus aff. *clavipes*		F				
Tripodiscinus kaptarenkoe			C		R	
Tripodiscinus aff. *tribrachiatus*		F				

TABLE 4. — Stratigraphic range chart of diatoms and silicoflagellates in Sergeevka Section. Legend: see Table 1.

Species/sample number	9	19	20	22
Diatoms				
Arachnoidiscus ehrenbergii	F		F	
Arachnoidiscus asteromphalus			R	
Aulacodiscus excavatus	C	F	F	F
Azpeitia aff. *oligocenica*				R
Brightwellia imperfecta (?)				R
Corona retinervis			F	
Coscinodiscus bulliens				F
Coscinodiscus obscurus	C	C	C	C
Coscinodiscus obscurus var. *cancavus*		C	C	F
Cosmiodiscus breviradiatus				F
Coscinodiscus patera (?)				R
Craspedodiscus moelleri	F	R	F	R
Cristodiscus (*Coscinodiscus*) *succinctus*	R	F	F	A
Cristodiscus crux		F		
Cristodiscus decrescenoides		F	A	
Hemiaulus polymorphus var. *charkovianus*		F		F
Hyalodiscus radiatus		F	F	R
Hyalodiscus inflatus	C			
Hyalodiscus johnsonii	R	F		
Hyalodiscus kelleri var. *fasciculatus*	C	F	F	
Melosira architecturalis		F	C	
Melosira fausta	F	F		
Paralia oamaruensis	C	C	C	C
Paralia sulcata var. *sibirica*		C		
Peponia barbadensis	R			
Pseudopodosira hyalina	F	C		
Pseudopodosira bella		F	F	
Pseudopodosira westii	F	C		
Pseudotriceratium chenevieri				R
Pseudotriceratium pyleyformis		F		
Pyxidicula charkoviana	F	A	C	F
Pyxilla gracilis			F	
Pyxilla schenkii		R		
Pyxilla tchernovii		R		
Trinacria excavata			F	F
Triceratium aff. *kanaya* var. *trilobata*	R		F	
Triceratium ventricosa	C	C		
Silicoflagellates				
Dictyocha spinosa			F	
Distephanus pentadonus		F		
Distephanus grunowii		R		F
Naviculopsis constricta		F		
Naviculopsis oamaruensis	F			

TABLE 5. — Stratigraphic range chart of nannofossils in Kantemirovka Section. Legend: see Table 1.

Species/sample number	27	28	29	30	33
Blackites spinosus	F	F	F		
Chiasmolithus solitus	F	F	F	F	
Chiasmolithus tituf	F	F			
Coccolithus formosus	A	C	R	F	F
Cyclicargolithus floridanus	C	A	C	R	F
Discoaster barbadiensis	C	F			
Discoaster bifax	R	F			
Discoaster binodosus	R	F	F	F	
Discoaster deflandreis	R	F	F		
Discoaster saipanensis	F				
Discoaster strictus	F	F	F		
Discoaster onustus	R	F			
Helicosphaera bramlettei	F	F		F	
Helicosphaera seminulum	F				
Nannotetrina cristata	F	F			
Neococcolithes dubius	C	R	F		
Pontosphaera multipora	F	F	F		
Pontosphaera duocavus	F	F			
Reticulofenestra coenura	A	R	F	F	F
Reticulofenestra haqii	A	A	C	F	
Reticulofenestra umbilicus	C	R	F	F	
Sphenolithus moriformis	F	F			
Sphenolithus obtusus		F	F		
Sphenolithus radians		F			
Transversopontis pulcher		F	F	F	
Zygrhablithus bijugatus		R	F	F	F

TABLE 6. — Stratigraphic range chart of foraminifera in Kantemirovka Section. **b**, benthos; **p**, plankton. Legend: see Table 1.

Species/sample number		27	28	29
Acarinina rugosoaculeata	p	F		
Bolivina cookei	b	F	C	
Bulimina sculptilis	b		C	
Clavulina colomi	b	C	C	C
Clavulina cylindrica	b	C	C	C
Clavulinoides szaboi	b	A	A	C
Globigerinatheka index	p		R	
Pseudoclavulina subbotinae	b	F	F	C
Pseudohastigerina micra	p	F	C	
Spiroplectammina pishvanovae	b	F	C	
Subbotina turcmenica	p		C	A
Vaginulinopsis decorata	b	F	C	C
Uvigerina costellata	b	C	C	
Uvigerina macilenta	b	C	C	
Uvigerina spinocostata	b	C	C	

TABLE 7. — Stratigraphic range chart of radiolaria in Kantemirovka Section. Legend: see Table 1.

Species/sample number	39	40	41	42	43	44A
Bathropyramis aneotos			F			
Calocyclas asperum		R	R	R	R	
Calocyclas semipolita			R	R		
Ceratospyris sp. aff. *T. crassipes*		R				
Clatrocyclas extensa multiplicata		R		R		
Clathrocyclas talwanii	R	R	R	R		
Clathrocyclas sinitzini			F		F	F
Clathrocyclas sp. 1			R			
Conocaryomma sp.				C		
Cyrtophormis alta	C					
Heliodiscus heliasteriscus			A		A	
Heliodiscus zonatum			C			
Heliodiscus fragilis			C	F		
Heterosestrum formosum			A			A
Heterosestrum tschuenkoi						A
Hexacontium aff. *pachydermum*			A	C	C	C
Lithelius foremanae						C
Lithomelissa sp. A	C	A	A	A		C
Lithomelissa sp. B						C
Lithelius foremanae						C
Melittosphaera magnoporulosa			C	R		
Pseudodyctyophimus sp.				C		
Stylodyctya irregulare			C			
Stylosphaera coronata			F	F	F	F
Theocyrtis lithos						
Theocyrtis andriashevi						
Tripodiscinus kaptarenkoe			R	R	A	A
Velicucculus aff. *oddgurneri*		R				
Tripilidium clavipes						
Stylosphaera balbis						F
Tripodiscinus sp.						A

TABLE 8. — Stratigraphic ranges chart of diatoms and silicoflagellates in Kantemirovka Section. Legend: see Table 1.

Species/sample number	39	40	42	43	44A
Diatoms					
Aulacodiscus excavatus	F	F			F
Aulacodiscus kelleri var. *fasciculatus*				F	F
Arachnoidiscus ehrenbergii		F	F		F
Brightwellia coronata			R		
Cerataulus deflandrei		F			F
Corona retinervis			F	F	
Coscinodiscus obscurus	F	F	C	C	
Coscinodiscus obscurus var. *cancavus*	F	C	C	C	C
Coscinodiscus asteromphalus				F	
Coscinodiscus decrescenoides			C	F	C
Cristodiscus (Coscinodiscus) succinctus		F	C	C	
Hemiaulus polymorphus var. *charkovianus*	C			F	F
Hemiaulus tchernovii				F	F
Hemiaulus polycystinorum		F			F
Melosira architecturalis			C	C	F
Paralia sulcata var. *sibirica*		C	C	C	C
Paralia oamaruensis		C	C	C	F
Pseudopodosira hyalina		C	C	C	C
Pseudopodosira pyleiformis			C	C	F
Pyxilla gracilis		F			F
Pyxidicula charkoviana		F	C	F	F
Pyxidicula johnsonii				A	F
Pyxidicula aff. *moelleri*				F	F
Thalassiosiropsis wittiana				F	
Triceratium ventricosa		F		F	
Triceratium aff. *kanaya* var. *triloata*		R			R
Triceratium unguiculatum					R
Tricacria excavata var. *tetragona*				F	F
Silicoflagellates					
Dictyocha deflandrei				F	
Mesocena oamaruensis		F			
Naviculopsis constricta				F	
Naviculopsis foliaceae		F		F	

TABLE 9. — Stratigraphic range chart of nannofossils in Rudaevka (borehole 9540). Legend: see Table 1.

Species/sample number	**61-5**	**60-5**	**56**
Blackites spinosus	C		
Chiasmolithus grandis	F		
Chiasmolithus solitus	C	F	F
Chiasmolithus tituf	F	F	F
Clathrolithus spinosus	F		
Coccolithus formosus	R		F
Coccolithus pelagicus	R	R	R
Cyclicargolithus floridanus	A	A	C
Discoaster barbadiensis	F		F
Discoaster bifax	F		
Discoaster distinctus	R	F	F
Discoaster nodifer	R	F	F
Discoaster saipanensis	F		
Discoaster strictus	R		
Helicosphaera bramlettei	F		
Helicosphaera lophota	F		
Neococcolithes dubius	C	F	F
Pontosphaera duocavus	F		
Pontosphaera multipora	F	F	
Reticulofenestra umbilicus	C	F	F
Rhabdosphaera gladius	F		

TABLE 10. — Stratigraphic range chart of radiolaria in Rudaevka (borehole 9540). Legend: see Table 1.

Species/sample number	**60-5**	**59**	**53-5**	**51**	**50**	**49-5**	**47**	**45**	**43-5**	**39**	**35**	**33**
Stylodyctya hastata	F			F							F	R
Cenosphaera mitgarzi							A	A	C			
Thecosphaera minor	R											
Heliodiscus heliasteriscus	F		C	C							F	R
Clathrocyclas principi principi	R											
Lithomelissa sp. A	F											
Stylotrochus sp.	F			F								R
Hexacontium pachydermum			C	C								
Stylodyctya irregularis										A	C	A
Petalospyris aff. *dubia*			F									
Clathrocyclas extensa			F									
Theocorys reticula			F	F							F	
Heterosestrum formosum			F	C							C	F
Heterosestrum tschuenkoi			F	C	R							
Stylosphaera coronata laevis				F								
Tripodiscinus tumulosus				F								
Hiphospira ocellata				F								
Thecosphaera californica				F								
Lithomelissa aff. *haeckeli*				F								
Cenosphaera micropora												F
Cyrtophormis altus					R							
Perypyramis circumtexta							R					
Calocyclas semipolita												F
Lophophaena sp. B												A
Heliodiscus zonatus												C
Theocyrtis andriashevi												C

TABLE 11. — Stratigraphic range chart of diatoms and silicoflagellates in Rudaevka (borehole 5420). Legend: see Table 1.

Species/sample number	60-5	53-5	50	47	38	37	35	34	33	32
Diatoms										
Aulacodiscus excavatus	F									F
Aulacodiscus kelleri var. *fasciculatus*			F							
Cerataulus deflandrei		F								
Corona retinervis		F								
Coscinodiscus bulliens		F						F		
Coscinodiscus obscurus	F	F			C	C	C	C	C	R
Coscinodiscus obscurus var. *cancavus*		C	A		F		C	C	C	
Coscinodiscus asteromphalus									F	
Coscinodiscus decrescens									F	F
Coscinodiscus decrescenoides				F				F		F
Cosmiodiscus breviradiatus									F	
Cristodiscus succinctus		F								
Cristodiscus duplex	F									
Craspedodiscus moelleri						F				
Craspedodiscus oblongus						C				
Hemiaulus polymorphus var. *charkovianus*		F						F	F	C
Hemiaulus tchernovii			F							
Hyalodiscus radiatus				F						
Melosira architecturalis		C		F		F				
Paralia oamaruensis	C					C		F		C
Pseudopodosira hyalina		F	C			C	C			C
Pseudopodosira westii								F		
Pseudopodosira pyleyformis						C	F			F
Pseudopodosira bella		F								
Pyxilla gracilis		F								
Pyxidicula charkoviana	F	C	C				C			
Pyxidicula grunowii						F				
Pyxidicula aff. *moelleri*	F		C		F	F	F	F	F	F
Pyxidicula johnsonii				F						
Pyxidicula marginata							R			
Pyxidicula megapora										F
Triceratium kanaya var. *trilobata*							F	F		
Triceratium ventricosa										
Tricacria excavata										
Silicoflagellates										
Corbisema hastata globulosa										F
Corbisema triacantha		F								F
Dictyocha deflandrei										F
Dictyocha spinosa										
Distephanus pentadonus	F									
Naviculopsis foliaceae										C
Naviculopsis constricta										C
Naviculopsis nordica										C
Corbisema triacantha										F

TABLE 12. — Stratigraphic range chart of radiolaria in Boguchar (borehole 5-93). Legend: see Table 1.

Species/sample number	**63-4**	**62-1**	**60-1**	**31-5**	**31**	**30**	**23-4**	**17-4**	**16**	**12**	**11**
Thecosphaera californica	F										
Calocyclas semipolita	C										
Heliodiscus heliasteriscus	C										
Lychnocanium bellum	F										
Artostrobus aff. *annulatus*	F										
Stylodyctya irregularis	A										
Petalospyris dubia	C	F									
Lithomelissa haeckeli		F	F								
Hexacontium pachydermum		R	F	F	F	F			F		
Hexacontium sp.											
Spongomelissa sp. 1			C								
Lithomelissa sp. A											
Stylosphaera coronata coronata			C	F							
Heliodiscus dupla			F								
Tripodiscinus aff. *vanus*	F										
Heterosestrum formosum			C								
Stylotrochus radiatus	C	C	C								
Heterosestrum thcuenkoi			R								
Heterosestrum shabalkini								R			R
Clathrocyclas talwanii											
Cenosphaera mitgarzi							F	F			
Theocyrtis lithos				C							R
Theocorys reticula				A							
Artobotrys norvegiensis				F							
Lithomelissa stigi							C				
Peripyramis anoetum				R							
Lithelius spiralis				R		C	C	C			
Thecosphaera minor									R		
Cyrtophormis alta					C	R			F		
Tripodiscinus tribrachiatus							F	F	R		
Tripodisciunus kaptarenkoi							F	C			
Theocyrtis andriashevi							R	F	F		
Haliomma immensa							A				
Calocyclas asperum						R		C			
Rhodosphaera donensis					R	C					

TABLE 13. — Stratigraphic range chart of diatoms and silicoflagellates in Boguchar (borehole 5-93). Legend: see Table 1.

Species/sample number	63-4	62-1	60-1	29-5	28-2	24-2	17-1	15-1
Diatoms								
Actinoptychus intermedius		F			F			
Aulacodiscus excavatus	F							
Aulacodiscus kelleri var. *fasciculatus*	F							
Aulacodiscus inflatus		R						
Azpeitia aff. *oligocenica*			F					
Brightwellia sp.			R					
Cerataulus deflandrei	F					F		
Corona retinervis			F			F		
Coscinodiscus bulliens	F		F			F		
Coscinodiscus obscurus	C	C					F	F
Coscinodiscus obscurus var. *cancavus*	F	C	C					
Coscinodiscus asteromphalus			R					
Coscinodiscus decrescens	F							
Coscinodiscus marginatus					F			
Coscinodiscus decrescenoides	F		F					
Cosmiodiscus breviradiatus						F		F
Cristodiscus succinctus	F				F			
Cristodiscus duplex	F					F		
Craspedodiscus moolleri						F		
Craspedodiscus oblongus				F	C	C		
Hemialus polycystinorum	F			F		F		
H. polymorphus var. *charkovianus*	F					F	C	
Hyalodiscus radiatus	R		F			F		
Melosira architecturalis	F	F		F	C	C		
Paralia sulcata var. *sibirica*	C	C						
Paralia oamaruensis	F	C				R		
Pseudopodosira hyalina	C				F	C	C	F
Pseudopodosira pyleyformis	F		F		C		F	
Pseudopodosira bella					C			
Pyxilla gracilis	F				F	F		
P. oligocenica var. *oligocenica*					F	F		
Pyxidicula charkoviana	F	F	F	C		C		
Pyxidicula grunowii				F				
Pyxidicula aff. *moelleri*	F			F		F		
Pyxidicula johnsonii	F							
Pyxidicula crenata						F		
Pyxidicula megapora		F	F					
Pyxidicula spinodissima					R			
Stellarima mucrotrias	F		F					
Triceratium ventricosa			F	F		C		
Triceratium aff. *kanaya* var. *triloata*						F		
Tricacria excavata	F		F			F		
Tricacria exsculpta					F			
Silicoflagellates								
Corbisema hastata globulosa								F
Corbisema enermis								F
Dictyocha deflandrei	F							
Dictyocha spinosa								F
Dictyocha hexacantha						F		
Distephanus pentagonus			F					
Naviculopsis foliaceae								C
Naviculopsis constricta								F
Naviculopsis nordica								C

Some peculiarities concerning the Pliocene evolution of the Black Sea and Caspian basins

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KEY WORDS
Petromagnetism,
scalar magnetic characteristics,
magnetic susceptibility,
Para-Tethys,
Pliocene.

ABSTRACT

This paper presents the results of petromagnetic studies on Pliocene key sections of Crimea, Georgia, the Apscheron Peninsula and the North Cis-Caspian Region. Scalar magnetic characteristics of sedimentary rocks reflects the conditions they have been formed in the eastern Para-Tethys. The Pliocene activation is recorded by increased rock magnetism in the middle Pliocene. The dependence of petromagnetic variations upon tectonic factors allows to correlate the marine Pliocene succession from the Ponto-Caspian District.

MOTS CLÉS
Pétromagnétisme,
caractéristiques magnétiques scalaires,
susceptibilité magnétique,
Para-Téthys,
Pliocène.

RÉSUMÉ

Quelques particularités de l'évolution pliocène des bassins de la Mer noire et de la Caspienne.

Cet article présente les résultats d'études pétromagnétiques des dépôts pliocènes de Crimée, de Géorgie, de la péninsule d'Apscheron et de la région nord de la Cis-Caspienne. Les caractéristiques magnétiques scalaires des roches sédimentaires reflètent les conditions dans lesquelles elles ont été formées dans la Para-Téthys orientale. L'activation pliocène est enregistrée par une augmentation du magnétisme au Pliocène moyen. La dépendance des variations pétromagnétiques vis à vis des facteurs tectoniques permet la corrélation des dépôts marins de la région Ponto-Caspienne.

INTRODUCTION

Tectonic activity of the Caucasus and adjacent mountain areas at the Miocene-Pliocene transition has speeded up the disintegration and final disappearance of the Para-Tethys Basin. The western Para-Tethys disappeared and the eastern Para-Tethys was ultimately disintegrated at the end of the early Pliocene, which resulted in the final isolation of the Pontic and Caspian seas (Nevesskaya *et al.* 1986).

Since their development proceeded practically independently, though occasional reunification through the system of latitudinal Kuma-Manych depressions was established. The geologic record of the Caspian water break-through into the Cis-Pontic Region at the end of the middle Actchagylian (the beginning of Matuyama epoch) is most clearly demonstrated by the beds with common mollusc fauna: Tamanian beds containing the Actchagylian *Cardium* in the Cis-Pontic Region and the Pontic *Dreissenia* within the Actchagylian of the Caspian Section (Kitovani 1976; Nevesskaya *et al.* 1986; Zubakov 1990).

The general evolution scheme of isolated Peri-Tethys basins was traditionally based on lithofacies and palaeontological data. Palaeomagnetic research, especially after Harland *et al.* (1982) magnetochronologic scale, provided the framework for more solid and precise correlations of geologic events in the Black Sea and Caspian regions. Recent research have demonstrated that most interesting stratigraphic, palaeogeographic and geochemical information is to be found in scalar magnetic characteristics of sedimentary rocks; the "magnetic memory" of these rocks reflects the main events of their formation in various geodynamic and landscape-climatic settings (Molostovsky 1986; Guzhikov & Molostovsky 1995).

The results of palaeo- and petromagnetic re search of the marine Pliocene and Pleistocene from the Kerch Peninsula, western Georgia and Apsheron Peninsula are presented (Fig. 1).

In this study beside palaeontological, palynological and lithologic-mineralogical data, a substantial amount of original and previously published palaeomagnetic data was used for palaeogeographic reconstructions (Ali-Zade 1954; Khramov 1963; Asadulaev & Pevzner 1973; Trubikhin 1977; Zubakov 1990). The authors gathered the material on scalar magnetic characteristics and add data from Ismail-Zade (1967) and Khramov (1963).

Magnetic susceptibilities were measured by IMV-2 and KT-5 devices, remanent magnetisation – by spinner-magnetometers ION-1, JR-3, JR-4.

The basic palaeomagnetic material used for comparative analyses is summarised in a correlation scheme showing with the Pliocene stratigraphic units from the Black Sea and Caspian regions in relation to the general magnetostratigraphic scale (Fig. 2).

MAIN PRINCIPLES OF STRATIGRAPHIC INTERPRETATIONS OF PETROMAGNETIC DATA

Petromagnetic variations of sedimentary sequences are controlled by the depositional processes and boundary conditions that determine the formation of these units. Therefore, a subdivision of stratified rocks based on common scalar magnetic characteristics, has sedimento-stratigraphic significance.

The sedimentary rock magnetic properties are determined by both natural (magnetic susceptibility – k, modulus of natural remanent magnetisation – Jn, etc.) and artificial parameters i.e. measured after exposure to temperature and/or a laboratory magnetic field (magnetic susceptibility of a sample after exposure to temperature – dk, saturation magnetisation – Js, saturation field – Hs, etc.).

The values of natural petromagnetic characteristics – magnetic susceptibility (k) and natural remanent magnetisation (NRM, Jn) – depend mostly on ferromagnetic mineral concentrations as well as on magnetic phase compositions, secondary changes and others. The Jn modulus is mainly controlled by the degree of order of domain magnetic moments, which results in higher Jn in chemically magnetised rocks than in those with orientational magnetisation, while magnetic susceptibility values do no vary. In weakly magnetised rocks (k = $10\text{-}20.10^{-5}$ SI

FIG. 1. — Location map. **I**, Great Caucasus; **II**, Adjar-Trialet mountain system; **III**, Balkhan; **IV**, Kopet-Dag; **V**, Talysh Mountains. Sections: **a**, wells 1, 5, 13, 14, 15, 18, 19 (Samara Region); **b**, well 3 (Saratov, Volga Region); **c**, well 20 (Saratov, Volga Region); **d**, well 13 (Kalmykia); e, well 48 (Kalmykia); **f**, Kerch Peninsula; **g**, western Georgia.

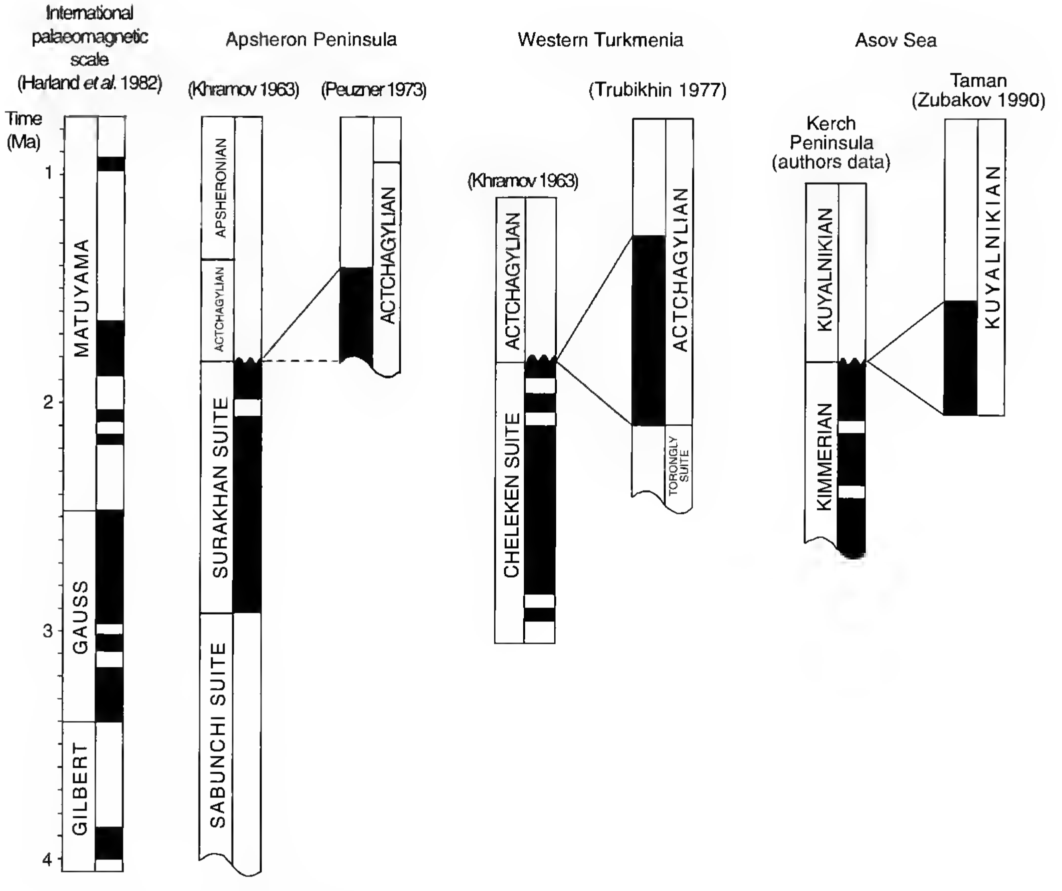

FIG. 2. — Correlation between palaeomagnetic sections of the Pliocene from eastern Para-Tethys.

units) paramagnetic components strongly affect k-value formation. All the petromagnetic indices are functionally associated with sediment composition, textural-structural rock features, palaeogeographic and geochemical sediment composition epigenetic changes, i.e., with all parameters controlling the formation of the large sedimentary complexes within concrete palaeobasins.

The obvious relationship between petromagnetism and sedimentation processes provides potentially a wide application of scalar magnetic characteristics in solving diverse geologic problems; the petromagnetic method can be considered as a form of rhythmostratigraphic analysis. Detailed knowledge of the ferromagnetic-fraction mineralogy forms the fundamental basis in the interpretation of such data.

A large amount of data on magnetic properties of sedimentary formations of diverse ages and genesis were summarised by the authors; this made it possible to formulate the main principles of palaeogeographic interpretation of petromagnetic indices. The essence of these principles accounts to:

1. Magnetic differentiation of rocks within a stratigraphic section is controlled by the changes in sedimentation environments.

In rocks with syn- or post-sedimentary magnetisation carried by allothigenic ferromagnetics, palaeogeographic and tectonic factors are definitive, i.e., those controlling terrigenous magnetic material erosion, transport deposition (tectonic activity, climatic changes affecting the rate of baring processes). The increased concentration of

detritic ferromagnetics is registered by k and Jn bursts on petromagnetic curves.

In rocks with chemically introduced NRM contained by authigenic minerals, magnetic properties are controlled by the geochemical environment during the formation of the authigenic magnetic phase. For example, in reducing conditions due to some sulphur deficit, authigenic sulphide mineralisation is observed within the sediments with strongly magnetised pyrrhotine and greigite being formed together with pyrite. Variations in geochemical conditions may result in variation in different distribution of magnetic sulphides within a stratigraphic section, which is registered by changes in magnetic susceptibility and natural remanent magnetisation.

2. The levels of substantial changes in sedimentary sequence magnetism constitute the natural interfaces between real stratiform bodies, and the petromagnetic layer-sets themselves may be classified as stratigraphic units of local or regional importance.

3. Sediment petromagnetic differentiation in time is of regular character and reflects sedimentation peculiar and reflects changes in sedimentation processes and environment. Spasmodic petromagnetic changes generally coincide with sharp changes in sedimentation.

4. Petromagnetic rhythms within periods of erosion or non-deposition parallel sedimentation rhythms.

In case of detrital nature of Jn, the initial (regressive) stages of sedimentation cycles are marked by a drop in magnetisation. When magnetic rhythm is controlled by changes in palaeogeochemical conditions significant increases in Jn and k are observed in deep-water sediments, containing authigenic phases – pyrrhotine and greigite, which formed under the reducing conditions.

5. Petromagnetic variations, observed after heating of samples in laboratory, reflect concentration variations in originally non-magnetic or weakly magnetic ferriferous minerals (pyrite, marcasite, siderite, iron hydroxides). These minerals are clearly recorded magnetometrically after conversion under elevated temperature.

Pyrite and marcasite, for example, when heated up to 500 °C in oxidising medium, turn into magnetite, which results in magnetic susceptibility increase. The increase in $Dk = k_T$-k reflects the content of newly-formed magnetite, and thus, concentrations of initial FeS_2.

If non-magnetic iron sulphides are of authigenic nature, the abnormally high increase of magnetic susceptibility mirrors the reducing environment in a sedimentary basin, with the presence of hydrogen sulphide; dk – curve variations form the basis for detailed sequence division and let yield constrain on the changes in redox potentials of sedimentation environment.

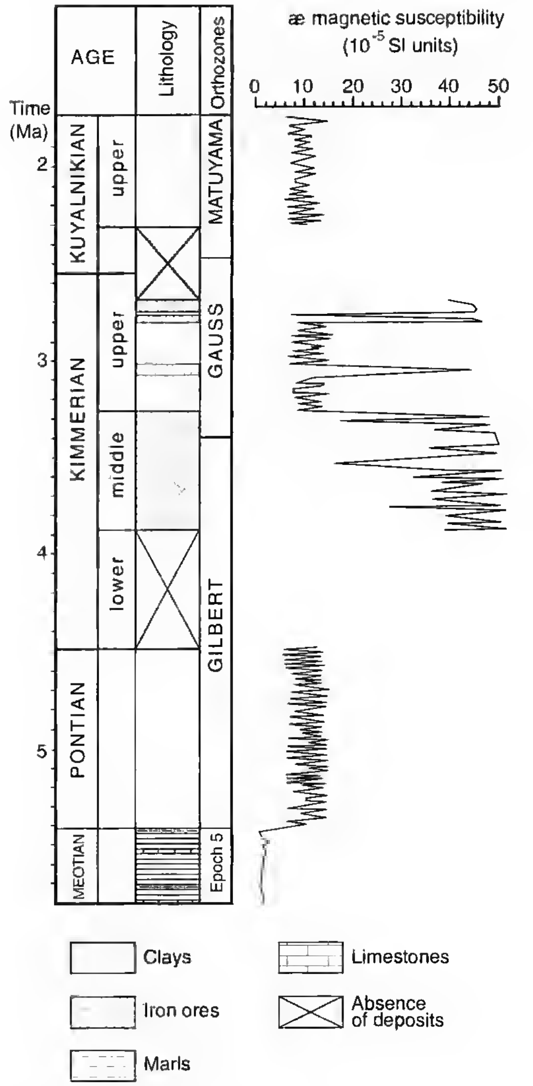

FIG. 3. — Synthetic petromagnetic curve of Pliocene deposits of the Kerch Peninsula.

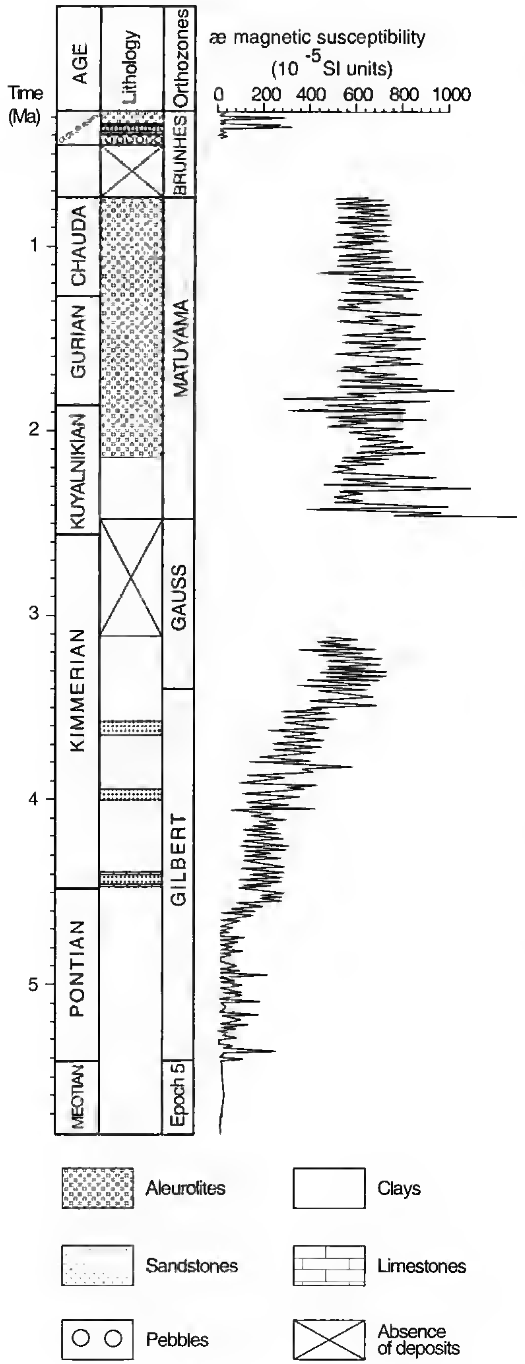

FIG. 4. — Synthetic petromagnetic curve of Pliocene and Pleistocene deposits of western Georgia.

INVESTIGATION RESULTS

KERCH PENINSULA

Reconstruction of palaeogeographic events on the basis of the palaeo- and petromagnetic data of the Black Sea Region, is possible from the end of the Miocene to the beginning of the Pliocene. The analyses of several composite sections through the Meotian and Pontian beds in Kerch Peninsula demonstrate that similar changes in magnetic properties can be observed in sediments from various parts of the basins.

Clayey-carbonate deposits of Meotian age in the north-western Cis-Pontic Region are ubiquitously distinguished for extremely low and homogeneous magnetisation. Their magnetic susceptibility varies between 3 and 8.10^{-5} SI units.

The beginning of the Pontian transgression in the large Euxinic Basin was accompanied by accumulation of dark-grey deep-water clays, dominating practically in all the sections from western Georgia and Kerch-Taman regions. The beginning of the Pliocene is everywhere marked by substantial changes in marine sediment petromagnetism.

Within the Pontian beds of Kerch Peninsula, the level of magnetisation is at least two times higher than in the Meotian terrigenous-carbonate sequence. Modal k values, here, are as high as 15.10^{-5} SI units (Fig. 3).

During the Kimmerian, deep-water clay accumulated. These clays contain intercalations of chemogenic siderite-leptochlorite ores in the middle part of the section which was deposited in the Kerch and Taman areas. The interlayers resulted from erosion and transport to the littoral zone of the local laterite crusts of weathering (Zubakov 1990).

The increased iron-salt contents in the middle Kimmerian sediments had relatively small influence upon their magnetic properties due to the absence of strong magnetic phases. Magnetic susceptibilities in iron ores are increased (20-55.10^{-5} SI units) relative to those of the host rocks ($k_{mod} = 12.10^{-5}$ SI units).

Break of erosion of the laterite-crust at the end of the Kimmerian is recorded by a marked magnetisation decrease in the rocks of the upper

Kimmerian and Kuyalnikian where the k values do not exceed 14.10^{-5} SI units (Fig. 3).

WESTERN GEORGIA

Petromagnetic differentiation in western Georgia is much more marked than in the north-western Cis-Pontic Region, in spite of the homogenous character of the section composed of grey deep-water clays, with some sandstones and aleurolites.

The Meotian/Pontian boundary is recorded as a clear change in petromagnetic response of the sequence (Fig. 4). In western Georgia, the Meotian clayey-aleurolitic sequence is also distinguished for low magnetisation: $k_{mod} = 20.10^{-5}$ SI units. Magnetic susceptibility values are significantly higher in the lower part of the Pontian section; they vary between $20\text{-}200.10^{-5}$ SI units. Sediment magnetisation increases steadily upwards along the section, and within the upper horizons of the Pontian, the k values vary between $k = 40\text{-}300.10^{-5}$ SI units.

Magnetic susceptibility values increase up to $200\text{-}800.10^{-5}$ SI units, in the Kimmerian, reaching the maximum in the clays and aleurolite of the Kuyalnik, Gurian and Chaudian horizons: $k = 300\text{-}1300.10^{-5}$ SI units ($k_{mod} = 660.10^{-5}$ SI units).

In the Pleistocene, the transport of terrigenous magnetic material decreased significantly, its input to the ancient Euxinic Basin was more episodic. This is marked by alternation of strongly and weakly-magnetised layers in the petromagnetic records. In weakly magnetised sediments the k values vary between 9 and 40.10^{-5} SI units, in strongly magnetic sediments $k = 80\text{-}320.10^{-5}$ SI units (Fig. 4).

Thick (up to 3500 m) Pliocene deposits with unique magnetic properties, were formed in western Georgia at the end of the Cainozoic. Judging from petromagnetic data, the processes of marine accumulation in this region were mainly controlled by intensive ascending movements of the western part of the Great Caucasus and Adjar-Trialet Mountain system. Their activity is usually correlated with the middle/late Pliocene transition (Kitovani 1976) but the petromagnetic record clearly indicates that tectonic activity started as early as the earliest Pliocene.

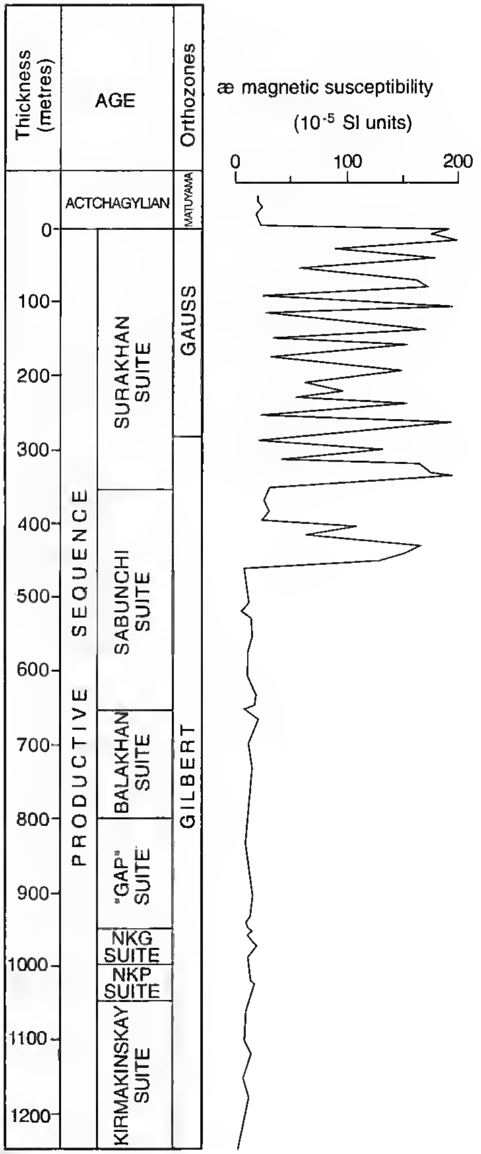

FIG. 5. — Synthetic petromagnetic curve of Pliocene deposits of the Apsheron Peninsula (Khramov 1963; Ismail-Zade *et al.* 1967).

Magnetic material was mainly provided by the Eocene volcanic covers, widely spread in the southern regions of Georgia. The erosion of highly-magnetic sequences in the mountains continued with increasing intensity right up to the end of the Pliocene. Baring rates seemed to have decreased in the Pleistocene, but the presence of magnetite-saturated beach sands in the vici-

nity of the towns of Poti, Ureki and Magnetiti (Guria) suggest that the process continue.

Petromagnetic section correlation with the magnetochronologic scale suggests that the Adjar-Ttialet Mountain massif is the most active geodynamic centre of the Black Sea region for the last 5.4 Ma: intensive bating continues since the beginning of Gilbert epoch (Fig. 4).

The transgtessive-regressive variations of the Euxinic Basin, contrary to the north-western Cis-Pontic, are not clearly reflected in the Georgian sections, though they are easily recognised from numerous unconformities within the Pliocene sequence. The most expressive trace was left by the Kimmerian activation, which resulted in strong reduction of Gauss zone in many sections.

Caspian Region

No petromagnetic data on the lower Pliocene from the Caspian Region is available. In the middle Pliocene portion of the scale, the productive sequence from Apsheron Peninsula is relatively well studied, as well as its correlative red-bed (Cheleken) suite from western Turkmenia (Khramov 1963). These rock complexes were deposited in semi-freshwater basins with intensive terrigenous sedimentation; the basins originated in the Caspian Region during the Kimmerian transgression of the Euxinic Basin (Muratov & Nevesskaja 1986).

The Kimmerian tectonic event did not leave any notable traces in the petromagnetic section from the Trans-Caspian due to the lack of highly magnetic source rocks in the western Kopet-Dag and Balkhan. The redstones, aleurolites and clays of the Cheleken suite are generally characterised by moderate magnetisation (k = 15-25.10^{-5} SI units) and are poorly differentiated along the stratigraphic section (Khramov 1963).

The petromagnetic section through the productive sequence from Azerbaijan is more informative in this respect (Fig. 5). According to Khramov (1963) and Ismail-Zade *et al.* (1967) data, the lower part of this large terrigenous complex (~800 m) is composed of low-magnetised clays, aleurolites and sandstones with the average k va 13.10^{-5} SI units. In the upper part of the Sabunchi suite, a sharp magnetisation increase is observed in all rock varieties, accompanied by a substantial dispersion of scalar magnetic characteristics: k = 13-160.10^{-5} SI units (k_{mod} = 75. 10^{-5} SI units). A similar magnetisation level is charactetistic of the overlying Surakhan suite; the overall thickness of the highly magnetic complex constitutes up to 450-500 m (Fig. 5).

The large volumes of magnetic material transported to the regressing Balakhan reservoir might have been caused by the increased tectonic activity of the eastern flank of the Great Caucasus or the Talysh Mountain massif in the southern Cis-Caspian. In any case, the intensive baring of Mesozoic and Palaeogene volcanite sequences of intermediate and basic composition, resulted in the accumulation of magnetic material in the upper horizons of the productive sequences.

The Pliocene activity in the eastern Caucasus is dated rather precisely by the magnetostratigraphic scale (Fig. 5) as the end of Gilbert epoch plus the early Gauss, which approximately corresponds to the interval of 1 Ma.

Correlations of regional magnetostratigtaphic schemes and composite petromagnetic columns show, that notwithstanding the complete isolation of the Caspian and Euxinic basins in the middle Pliocene, the Kimmerian tectonic activation has similarly affected sedimentation throughout the whole of the eastern Para-Tethys.

In the north-western Cis-Pontic and Apsheron regions, this is marked by the clear enough petromagnetic effects in the sections through the middle Kimmerian (ore) and the Surakhan suite. In Kerch Peninsula, western Georgia, Azerbaijan and Turkmenia, an unconformity separates the upper horizons of the Kuyalnikian and Actchagylian from the Kimmerian super-ore sequence, Surakhan and Cheleken suites; the upper half of Gauss zone is not present in the section (Fig. 2).

All the authots analysing the Pliocene history of the Black Sea region, note the relative stability of the Euxinic configuration and its cotrespondence with the modern Black Sea area. It is only at individual stages of the eastern Para-Tethys evolution when large bays came into existence in the Kuban-Azov Region and Guria (Kitovani 1976; Nevesskaja *et al.* 1986).

The limited lateral amplitudes of the Euxinic

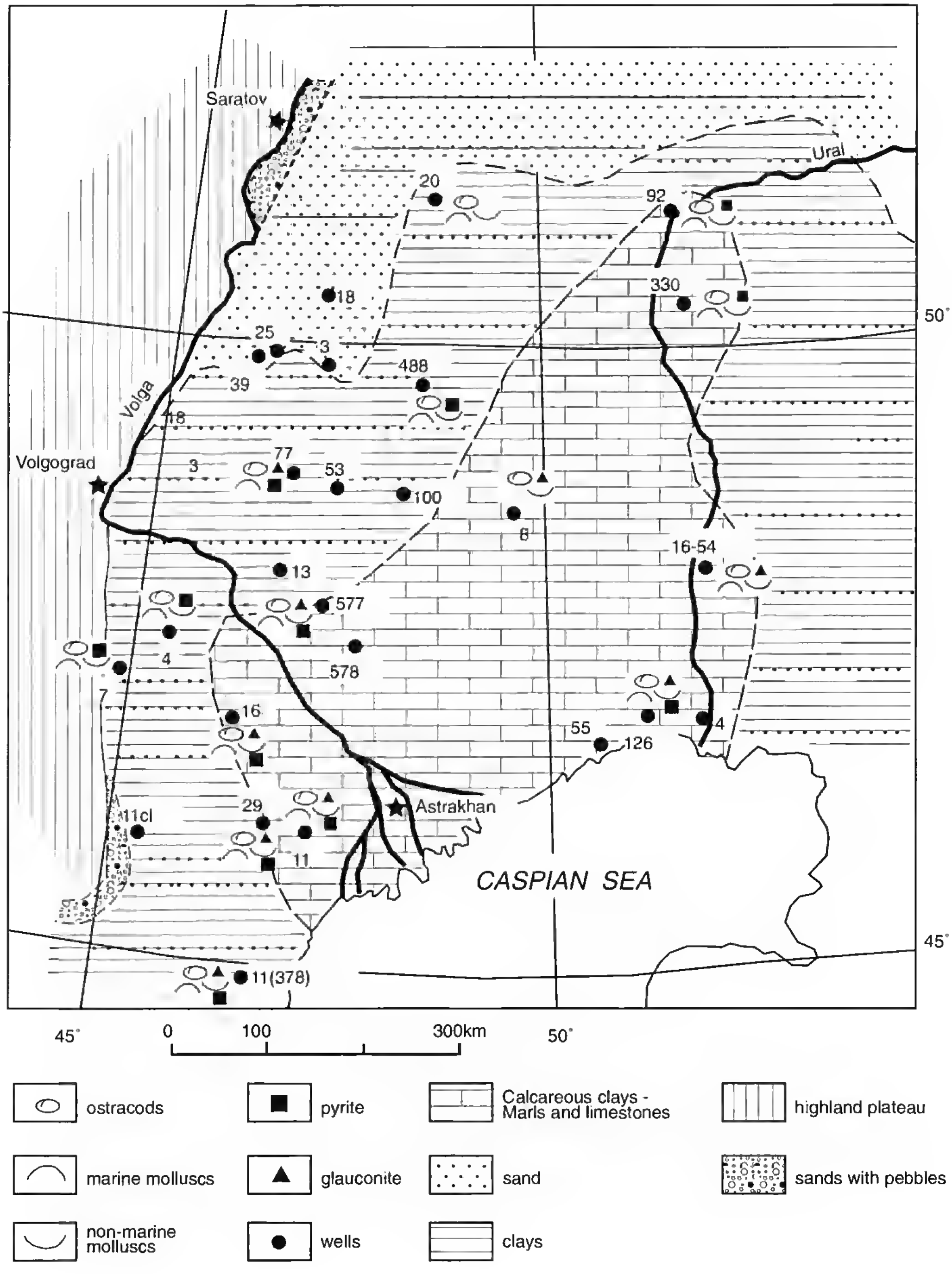

FIG. 6. — Lithological-palaeogeographical scheme of Actchagylian stage of the Caspian Depression (Akhlestina & Karmishina 1973).

transgressions with dominating plain savannah-steppe landscapes in the Cis-Pontic Region (Zubakov 1990) combined with the thick transgressive series indicate the tectonic quiescence in the region and limited erosion all over the northern fringe of the Euxinic.

It follows from Figure 3, that the Pliocene transgressions were accompanied by the changes in the magnetic properties of corresponding sediments. The amplitudes of petromagnetic variations themselves are insignificant, because only the upper, weakly magnetised horizons of the sedimentary cover have undergone erosion in the sourceland. The large volcanic massif of the Kara-Dag (southern Crimea) evidently did not serve as a source area for the northern Euxinic Basin in the Pliocene.

From palaeontological and lithofacies data, Kitovani (1976) concluded, that the Kuyalnikian age represented the turning point in modern history of the Black Sea region. It corresponds to the beginning of a major transgressive cycle that should be considered as the start of the late Pliocene.

This conclusion is supported by all data, but the basic importance of the Kuyalnikian (Actchagylian) stage for the evolution of the northern fringes of the Tethys is not limited to the Black Sea basins.

Palaeogeographic reconstructions show that the Neogene history of the Para-Tethys is characterised by alternating episodes of isolation and reunification of individual basins (Nevesskaya *et al.* 1986). All the geologic events of that period, accompanied by transgressions and regressions, occurred in the sublatitudinal direction between 40 and 50°N; the northern margin of the Peri-Tethys zone hardli ever crossed the conventional line between the present Volga Delta and the Taganrog Bay of the Azov Sea.

A fundamentally new geodynamic situation was formed at the beginning of the Actchagylian.

A number of large-scale transgressions have resulted in cardinal change of water-masses movement direction: from the sublatitudinal to the meridional one. A large brackish-water basin arised in the Caspian Region: it stretched from the southern shores of the modern Caspian Sea for more than 2000 km, right to the lower reaches of the Kama Rivet. This basin, nearly equal in its area to the whole of the Para-Tethys, lasted through the Apsheronian and disintegrated only in the early Pleistocene due to a major Tjurkian regression.

Facies of the Upper Pliocene were studied in detail in a number of papers (Kolesnikov 1940; Ali-Zade 1954; Asadulaev & Pevzner 1973; Trubichin 1977). Coarse-detrital sediments from 5-10 to 50-60 metres thick accumulated in littoral zones. Shallow-water sediments were deposited at moderate depths (down to 100 m); they are represented by alternating aleurolites and sandstones up to 400 m thick. Carbonates and deep-water clays with authigenic iron sulphides (pyrites and greigites) were deposited in the central parts of the reservoir under the conditions of hydrogen-sulphide contamination. Greigite is characterised by pronounced ferromagnetism and to a large extent determines the magnetic properties of the Pliocene marine deposits from the northern Cis-Caspian.

The facies variations of Actchagyl northern Cis-Caspian Basin are analysed by Akhlestina & Karmishina (1973) (Fig. 6).

The structures of the majority of the Cis-Caspian Pliocene sections studied in Kalmykia (well 13), Saratov Region (wells 3, 20), clearly reveal sedimentation rhythms, caused by alternating transgressive and regressive cycles. Each sedimentation rhythm comprises arenaceous (regressive) and argillaceous (transgressive) members with the average thickness as of 30-50 m. Judging from the data published, such a structure of the Pliocene sequence is common for the whole of the Volga and northern Cis-Caspian regions. Mineralogical analyses have established that the authigenic minerals pyrite-greigite association characterise the transgressive series, while siderite and iron hydroxides are characteristic of the regressive ones. Transgressive-regressive sedimentation phases in petromagnetic columns are registered by strong variations of scalar magnetic characteristics. In the transgressive portions of the elemental rhythms, Jn and k values vary, basically, within the ranges of $20\text{-}150.10^{-3}$ A/m and $100\text{-}500.10^{-5}$ SI units. In the regressive (arenaceous) facies, they decrease to $0.5\text{-}10.10^{-3}$ A/m and $10\text{-}30.10^{-5}$-SI units.

In some sections, composed of lithologically homogeneous sequences or closely interlayered rocks, magnetic parametrics becomes a more precise indicator of environmental changes in the deeper parts of the basin, than the traditional litho-facies methods.

The available data do not allow the establishment of the total number of elemental sedimentation rhythms within the Cis-Caspian Actchagylian-Apsheronian sequence, since this number may vary with the section completeness and sedimentation conditions.

The comparative analyses of petromagnetic data from wells 13 and 48 have revealed a quite clear correlation between the compositions of spore-pollen complexes and rock magnetisation. Highly magnetic transgressive portions of the rhythms are generally associated with the complexes of forest-steppe and forest types with the content of arboreal pollen as high as 50-65% and that of herbaceous pollen not exceeding 25-30%. The weakly magnetised regressive facies are characterised by steppe palynocomplexes dominated by herbaceous pollen (Sedaycin *et al.* 1987).

This indicates that the petromagnetic characteristics of the rocks, may mirror the climatic changes: alternations of relatively humid warm and cool arid periods.

The physical-mineralogic foundation of such interrelations are quite evident. In the moments of climatic optima, favourable conditions are created for production, drift and accumulation of substantial masses of plant organic matter; the burial of this matter gives rise to reducing conditions necessary to form authigenic sulphides in natural silts. As it follows from the available data, the transgressive phases in the Actchagylian and Apsheronian basins coincided with climatic optima.

The problem of correlations between climatic events and sedimenration settings in the Plio-Pleistocene basins of the eastern Para-Tethys form a long standing discussion. A wide range of ideas has been presented; various authors arrive at diametrically opposite conclusions on the basis of virtually similar data. Yakhimovich *et al.* (1985) correlate the Palaeo-Caspian transgressive stages with the Plio-Pleistocene climatic optima and the regressive stages with the periods of cooling in the Volga-Ural Region. Zubakov (1990), on the contrary, asserted that the Pliocene regressions of the Caspian Sea are related with the thermochrons, and the high stand stages – with cooling and aridisation in the Cis-Caspian Region.

Fedorov (1978, 1982), in his studies of the Pontic-Caspian palaeogeography, changed views more than once.

Petromagnetic data demonstrate, that the transgressive facies of elemental rhythms are associated with thermochrons, and the regressive ones with cryochrons. There is no support to correlate large transgressive cycles with climatic optima, because some information has been gained on multiple vegetation-community changes, and consequently, on climate oscillarions throughout each of the Pliocene transgressions.

In the Cis-Caspian, Volga and Cis-Ural regions, the period of the maximum middle Actchagylian transgression coincides with up to six changes of climatic conditions recorded by corresponding alternations of plant communities. Not less than eight climatic oscillations are revealed in the Apsheronian time from palynological data: four of them in the early and middle Apsheronian and four at the end of the middle and in the late Apsheronian (Yakhimovich *et al.* 1985). On the whole, at least fourteen climatic rearrangements took place during the four transgressive-regressive cycles of the late Pliocene.

The origin of the great Caspian transgressions presents one of the major problems in the Pliocene-Pleistocene history of the Para-Tethys and its northern borders. The majority of the authors relate them with water-balance changes in the basin in response to climatic change (Fedorov 1978; Zubakov 1990). A number of publications refer to the combined effects of tectonic and Late Cainozoic climatic events (Vostryakov 1973; Nevesskaya *et al.* 1986).

One crucial aspect should be considered while discussing this problem. The Actchagylian Stage in the evolution of the Pontic-Caspian was accompanied by a major change in the outflow system of between the Para-Tethys basins. A sharp reduction of sublatitudinal water-transfer took place, and a stable system of gigantic meridional movements of water masses set up.

No events of such magnitude are possible

without large structural rearrangements of the Earth crust, and the influence of the tectonic factor was probably decisive. Vostryakov (1973) paid particular importance to the regional neotectonic movements in territories of the Volga and northern Cis-Caspian regions, but fails to account for the Actchagylian transgression to western Turkmenia and the Aral Sea basin. It may be possible that the changes of transgressive-regressive cycles were controlled by the combinations of oscillatory motions of the southern Caspian deep-water part and the Russian Plate south-eastern periphery, the Peri-Caspian Depression included.

The dynamics of the Pliocene transgressions, exemplified by the middle Actchagylian, may be assessed as a first approximation magnetochronologically through correlation of regional palaeomagnetic columns. Trubikhin (1977) assigned the beginning of the middle Actchagylian transgression in Turkmenia to the middle of Gauss epoch - ~3 Ma (above Kaen episode). The northern limit of the middle Actchagyl sediments, corresponding to the end of Gauss epoch (~2.5 Ma), spreading is established in well 3 near the city of Saratov. Thus, during the 0.4-0.5 Ma – long interval, corresponding to the second half of Gauss epoch, the Actchagylian sea shore-line has shifted northwards for more than 1500 km, which corresponds to the average rate of 3 m per year.

CONCLUSION

Scalar magnetic characteristics of rocks reflect the conditions of the sedimentation; this allows to use petromagnetic data for palaeogeographic and geodynamic reconstructions. Sharp changes in sedimentary rock magnetisation serve as a direct indication for increased tectonic activity within source areas, resulting in new magnetic material. In the Late Neogene from the Black Sea region, a major petromagnetic boundary is associated with the Meotian/Pontian boundary.

An active input of magnetic material into the marine basin proceeded since the Late Pliocene, culminating at the end of the Pliocene. The Paleogene effusives of the Adjar-Trialet Ridge are known to be the main source for the south-eastern part of the Euxinic Basin; the Ridge is characterised by stable uplift for at least 5.4 Ma (since the start of Gilbert epoch to the present). Active uplift of the Main Ridge and, probably, the Talysh Mountains at the eastern end of the Caucasus began as late as at the end of Gilbert epoch and terminated in the early Gauss. The Mesozoic and Palaeogene effusives constituted the source of the magnetic material transported to the Balakhan Basin.

The transgressive-regressive cycles in the Euxinic and Caspian basins were significantly different in their magnitude. The Euxinic Basin did not change its outline notably during the whole of the Plio-Pleistocene.

The Euxinic Basin did not change its outline notably during the whole of the Pliocene, since the area extent of the incursions were rather limited. The Caspian transgressions, contrary to the Black Sea ones, resulted in the creation of vast basins.

The largest of them, the middle Actchagylian one, extended for more than 2000 km, from the southern margin of the Caspian Basin to the Kama River basin.

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